## NASA TECHNICAL TRANSLATION





# PROBLEMS OF ENGINEERING PSYCHOLOGY

B. F. Lomov, Editor

Papers presented at the First Leningrad Conference on Engineering Psychology, June 1964



#### PROBLEMS OF ENGINEERING PSYCHOLOGY

B. F. Lomov, Editor

Translation of "Problemy inzhenernoy psikhologii."
Papers presented at the First Leningrad Conference on
Engineering Psychology, June 1964.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information Springfield, Virginia 22151 - Price \$5.00



:	-	<u>-</u> -

Leningrad Branch, Society of Psychologists, Academy Pedagogical Sciences, Russian Socialist Federated Soviet Republic

Leningrad Institute for Scientific and Technical Propaganda

PROBLEMS OF ENGINEERING PSYCHOLOGY

B.F.Lomov, Editor

(Materials of the First Leningrad Conference on Engineering Psychology, June 1964)

Leningrad 1964

		!

#### TABLE OF CONTENTS

CENERAL TOPICS: SELF-ORGANIZING SYSTEMS; FUNCTIONS OF HUMAN BEINGS IN CONTROL SYSTEMS; GENERAL CHARACTERIZATION OF THE OPERATOR'S ACTIVITY; SIMULATION OF PSYCHIC ACTIVITY; RELIABILITY AND ACCURACY OF OPERATOR'S ACTIVITY; ENGINEERING PSYCHOLOGY AND ALLIED SCIENCES; DESIGN OF OPERATOR'S WORKING POST

	Page
A Study of the Process of Self-Organization, A.Ya.Lerner,	_
Yu.I.Shmukler (Moscow)	1
Influences, V.A.Berezin, V.M.Vodlozyerov, G.A.Sergeyev,	_
and G.V.Sukhodol'skiy (Leningrad)	1
Contribution to the Question of Transient Responses in Human Subjects, G.V.Sukhodol'skiy (Leningrad)	2
Contribution to the Question of the Functions of Human Beings	~
Participating in the Control of Nonregular Full-Scale	
Systems, D.I.Iordanskiy (Moscow)	3
Automation and Programming in Television Transmission,	
V.M.Pokorskiy and A.A.Stepanov (Leningrad)	3
Analysis of the Operator's Activity, V.P.Zinchenko and	
N.I.Mayzel' (Moscow)	5
Contribution to the Problem of Work of the Operator in	
Semi-Automatic Grading, V.N.Gorbatenko, G.V.Sukhodol'skiy and V.A.Shcherbakov (Leningrad)	6
and V.A. Shcherbakov (Leningrad)	U
the Mind, A.A.Bratko (Kiev)	6
Simulation of Certain Features of Mental Activity on	
Computers, A.G.Snytkin (Kiev)	7
Model of Automatic Adaptation to Changing Conditions of Work	
of the System "Man-Machine", N.N.Korobov (Kharkov)	8
Contribution to the Problem of the Reliability of Human	
Subjects (Regular and Random Failures in Operators	_
Work), M.I.Bobneva (Moscow)	9
Contribution to the Problem of Reliability (Working Capacity)	
of Human Subjects in Control Systems, K.S.Tochilov (Leningrad)	10
Contribution to the Investigation of the Functional State	10
of the Human Organism during Work, A.V.Dokvadze (Tbilisi)	11
Estimating Fitness for Work with Correcting Tables,	
S.I.Kopanov (Moscow)	12
Contribution to the Study of the Influence of Acceleration	
and Hypodynamia on the Reaction of Operators, A.R.Ko-	
tovskaya, V.K.Filosofov, N.A.Chekhonadskiy, and V.A.	3.0
Chichkin (Moscow)	13
Variations in Cortical Neurodynamics during Intense Mental Activity, G.K.Borisov (Leningrad)	13
MODIATOR GOVERNMENT TOO FINANCE TO THE TIRE OF THE CONTRACTOR OF T	エノ

•	Page
Dynamics of Variation of Certain Vegetative Functions in Railroad Dispatchers and Correlation with Psychic Mani-	
festations, G.K.Borisov (Leningrad)	15
Human Fatigue, Yu.M.Sten'ko (Moscow)	16
Long Voyages, P.A. Prosetskiy (Moscow)  Interaction of Accuracy and Stability in "Living Systems"	18
on Models of Static Adaptation, O.P.Kozerenko (Moscow)  Dependence of the Accuracy of Action on the Emotional	19
State, V.L.Marishchuk and N.V.Sysoyev (Leningrad)  Psychology of Linotype Operator's Errors and Their	19
Reduction, A.V.Filippov (Yaroslavl')  Engineering Psychology and Industrial Esthetics,	21
P.A.Kudin (Leningrad)	23
Ya.Neyshtadt (Moscow)	24
(Leningrad)  Principles of Evaluation of a Work Station According to	25
Engineering Psychology, L.V. Kuchevskaya (Moscow) Artificial Lighting of the Operator Work Station,	26
L.N.Meyer and A.G.Tishchenko (Moscow)	26
TRAINING AND SELECTION OF OPERATORS	
Training to Solve Control Problems, Ye.V.Voloshinova and G.K.Tvil†neva	27
(Leningrad) Study of the Effect of Nonspecific Training on the Ability to Process Information under Special Conditions,	28
V.M.Zatsiorskiy and O.P.Frolov (Moscow)  Specialized Physical Training of a Machine Operator,	28
T.T.Dzhamgarov and V.L.Marishchuk (Leningrad)	29
Panels, N.F.Fedotova (Leningrad)	30
Industrial Selection, V.A.Bobrov and J.M.Zarakovskiy (Leningrad)	32
GROUP ACTIVITY	
The Individual and the Group in Experimental Group	20
Psychology, F.D.Gorbov (Moscow)	33 34

mi umi a malu a a a a a a a a a a a a a a a a a a	Page
The "Time Sequence Test" as a Model of Expectation in Group Activity, V.T.Lebedeva (Moscow) Electrographic Study of the Effectiveness of Perception of a Signal in a Competitive Situation, V.I.Myasnikov	35
and I.P.Lebedeva (Moscow)	36
of Isolation, A.A.Koreshkov (Moscow)	37
METHODS OF INVESTIGATING HUMAN ACTIVITY. EXPERIMENTAL METHODS AND EQUIPMENT	
Application of the Methods of the Theory of Mass Servicing to the Problems of Engineering Psychology, L.V.Fatkin	
(Moscow)	39
Control, Yu.M.Porkhovnik (Leningrad)	40
and A.F.Romanenko (Leningrad)	40
(Leningrad)	42
logical Experiments, Yu.M.Baraboshkin (Moscow)  Study of the Interrelation of Steady States of the Physiological Functions by Means of a Digital Computer,	43
K.P.Buteyko and D.V.Demin (Novosibirsk)	44
Computers, K.P.Buteyko and D.V.Demin (Novosibirsk) Contribution to the Question of Automation of the Workup of Electroencephalograms, V.I.Kopanev and P.G.Shamrov	45
(Moscow)	46
Mental Fatigue from EEG Data, A.A.Genkin (Leningrad) Evaluation of the Functional State of an Operator in	47
Automatic Diagnosis, R.S.Dadashev (Moscow)	48
and S.G.Mel'nik (Moscow)  Contribution to the Question of the Methods of Evaluating the Psychophysiological State of a Pilot in an Emergency Situation during Flight, L.A.Kutayev-Smyk, I.P.Neu-	49
myvakin and V.A.Ponomarenko (Moscow)	49
of a Block Operator Point, V.F. Venda (Moscow)	50

	Page
Methods of Recording the Experimental Data Used in Studying Certain Questions of Engineering Psychology, V.I.Butov	
(Leningrad)  Contribution to the Technique of Studying Visuomotor  Reactions, Taking Account of the Features of Peripheral	51
Vision, Yu.N. Verkhalo (Leningrad)	53
A.B.Gandel'sman and Yu.N.Verkhalo (Leningrad)  Device for Experimental Study of the Speed of Information Processing by an Operator under Actual Conditions,	54
A.I.Galaktionov (Moscow)	55
RECEPTION OF INFORMATION BY HUMAN SUBJECTS: EVALUATION OF IN- FORMATION RECEIVED, SENSORY PROCESSES AND CHARACTERISTICS OF THE SENSORY SYSTEMS, SIMULATION OF PERCEPTION AND REC- OGNITION, CODING OF INFORMATION	•
Contribution to the Problem of the Quantitative Evaluation of Events of Complex Structure, A.I.Galaktionov (Moscow) How to Evaluate the Quantity of Information in Symbols,	56
when the Length of their Alphabet and the Probability of their Occurrence are Unknown, P.B.Nevel'skiy (Kharkov) Subjective Redundancy of Information Perceived by Man,	56
B.B.Kossov and R.A.Ratanova (Moscow)	58
Subject, G.V. Yeyger (Kharkov)	60
M.A.Dmitriyeva (Leningrad)	61
Yu.I.Ionin (Moscow)	62
the Accuracy of Perception, V.Ya.Dymerskiy (Moscow)  Time Characteristics of the Process of Detection and Identification of an Object in the Field of Vision,	63
Yu.B.Gippenreyter and L.P.Shchedrovitskiy (Moscow) Eye Movements in Visual Selection and Search, V.E.Mil'man	66
(Moscow) Study of the Operator's Work in Searching for Information when Performing a Task of Sequential Arrangement for	67
Service, Yu.B.Gippenreyter and G.N.Il'ina (Moscow) Experimental Study of Factors Influencing Perception by Peripheral Vision, N.D.Zavalova, V.A.Ponomarenko,	68
V.M.Sivolap, and L.A.Kitayev-Smyk (Moscow)	68
Extreme Conditions, V.V.Suvorova (Moscow)  Determination of the Sensory Threshold of the Human Auditory  Analyser by the Method of the Conditioned-Conditioned-	69

Unconditioned Reflex, G.F.Plekhanov, G.A.Aksenov, A.P.	Page
Voyarkina, V.V.Vedyushkina, L.P.Nagayev and Ye.I.Osinskaya (Novosibirsk)	70
Audition of Verbal Signals Transmitted Against the Background of White Noise, I.M.Lushchikhina (Leningrad)	71
(Leningrad)  Device for Automatic Recognition of Patterns as a Model	73
of Human Perception, V.A.Makhonin (Moscow) Simulation of Constant Properties in the Recognition of	73
Plane Figures, V.A.Makhonin and V.P.Savel'yev (Moscow) Contribution to the Question of the Optimum Coding of	74
Information Transmitted to the Operator of a Control System, B.F.Lomov (Leningrad)	74
G.V.Sukhodol'skiy (Leningrad)  The Role of Classification in the Recognition of Objects from their External Outline, V.A.Ganzen and	76
R.M.Granovskaya (Leningrad)	77
Recognition of Visual Displays on the Changes in their Angular Dimensions, M.K. Tutushkina (Leningrad) Visual Perception of a Display with Limited Presentation	78
Time, M.K. Tutushkina (Leningrad)  Selection of the Contrast Factor in the Perception of a	80
Visual Display, V.Ye.Bushurova (Leningrad)	81
Visual Display, T.P.Zinchenko (Leningrad) On the Measurement of Similarity in Graphic Images,	83
V.G.Stepanov (Moscow) Dependence of the Perception of Electronic Digital	84
Indicator Readings on the Illumination of the Indicating Portions, A.A.Krylov (Leningrad)	84
Divisions of Control-Measuring Devices, V.I.Nikolayev (Leningrad)	86
SENSORIMOTOR PROCESSES. REACTIONS	
On the Relationship between the Structures of the Sensory and Motor Regions in Control Operators,	
L.M. Vekker and Ye.N. Surkov (Leningrad)	87
Work of a Pilot, V.L.Marishchuk (Leningrad)	88
Hydrofoils, E.A.Belkina (Moscow)	90

	Page
Regulation of the Activity of an Operator Working under Conditions of Tracking, V.M.Vodlozerov	
and B.F.Lomov (Leningrad)  A Few Characteristics of an Operator's Work in Tracking and Pursuit of a One-Dimensional Signal, V.M.Vodlozerov	9:
(Leningrad)	9'2
Ye.A.Mileryan (Kiev)	91
Varying Illumination, S.N.Leviyeva (Leningrad)  The Effect of Pain Impulses on the Course of the Trace Processes in the Human Motor Analysor, L.P.Pavlova	96
(Leningrad) Asymmetry in the Manifestation of Muscle Sense,	97
Ye.P.Il'in (Leningrad) The Effect of Various Factors on Human Reaction Time, G.F.Plekhanov, V.V.Vedyushkina, L.P.Nagayev and	99
Ye.I.Osinskaya (Novosibirsk)  Effect of Attitude Toward a Task on the Speed of a Simple Sensorimotor Reaction, A.S. Yegorov and B.N. Yakovets	100
(Leningrad)  Speed of a Simple Sensorimotor Reaction under Unexpected Delays and Accelerations in the Tempo-Rhythm of Application of a Stimulus, A.S. Yegorov and	101
B.N.Yakovets Change in the Time Components of a Complex Reaction under the Influence of Unexpected Noise, Yu.Ya.Kiselev	102
(Leningrad)	104
A.N.Kozlov (Moscow)  Characterization of the Motor Component of the Sensorimotor  Reaction to Signals Forming a Binary Sequence,	105
V.A.Bodrov (Leningrad)  Speed of a Simple Sensorimotor Reaction to Nonsimultaneous and Simultaneous Action of Stimuli of Different	106
Modalities, A.S.Yegorov and B.N.Yakovets (Leningrad) Dependence of the Accuracy of Reaction to a Moving	107
Pointer on the Shape of the Dial and the Rate of Motion, S.A.Pauzhayte (Leningrad) The Systemicity of the Response Reactions in a Situation	108
of Choice, M.S. Yeritsyan and N.S. Kocharyan (Yerevan) On the Verbal Reproduction of a Chain of Successive Light Signals and Their Reflection on the Electro-	110
encephalograph, A.K.Astaf'yev (Leningrad)  Contribution to the Question of Evaluation of the Speed of Information Processing in Binary Serial	112
Reaction, V.A.Bodrov, A.A.Genkin and G.M.Zarakovskiy (Leningrad)	114

	Page
of Information Processing by an Operator, V.A.Yegorov (Leningrad)	116
the Study of the Motor Activity of Aircraft Pilots under Laboratory Conditions, V.A. Yegorov (Leningrad) Contribution to the Question of the Reactions of Choice	117
in Human Subjects, V.T.Prodan (Leningrad) Effect of Conditional Probabilities of a Sequence of	118
Signals on the Two-Choice Uniquely Determined Reaction, I.N.Krylov and K.A.Smirnov (Leningrad)	119
OPERATIVE THINKING. MEMORY.	
Contribution to the Comparative Analysis of the Process of Solving Problems on Electronic Computers and	
Human Intellectual Activity, O.K. Tikhomirov (Moscow)  Development of the Concept of Machine Thinking,	ואנ
A.M.Parachëv (Leningrad) On the Simulation of a Class of Intellectual Operations,	122
G.M.Khovanov (Moscow) On the Utilization of Chess as a Model of Operative	123
Thinking, V.N.Pushkin (Moscow)  Analysis of the Process of Solving Spatial— Combinatorial Problems of Discrete Character by the Aid of Motion Pictures of Eye Movements,	1 <i>21</i> ,
D.N.Zavalishina (Moscow)	126
Understanding of a Readily Visualized Situation, I.M.Geodakyan (Yerevan)	128
Features of Investigations of Thought in Engineering Psychology, A.M.Matyushkin (Moscow)	130
Contribution to the Problem of Operative Memory,	_
P.I.Zinchenko and G.V.Repkina (Kharkov)	132
of Symbols, P.I.Zinchenko and P.B.Nevel'skiy (Kharkov)	133
Memory Processes and the Coding of Information, N.I.Ryzhkova (Kharkov)	135
On the Composition and Dynamics of the Operators of Mnemic Activity, V.Ya.Lyaudis (Kharkov)	136
Comparison of Various Methods of Recognition,	138
M.S.Shekhter (Moscow)  Cognition in the Process of Solution of Operative	
Problems, D.N.Zavalishina and V.N.Pushkin (Moscow) On Tabular Assignment and Reorganization of Associative	14C
Memory, E.T.Golovan and V.S.Starinets (Kiev)	142

#### A STUDY OF THE PROCESS OF SELF-ORGANIZATION

A.Ya.Lerner, Yu.I.Shmukler (Moscow)

In this paper the authors investigate the mathematical description of the process of self-organization of a cybernetic system. The system is taken as an automatic data processing machine (probability automat) whose structure is described by a certain matrix of transient probabilities characterizing the representation of a set of stimuli (signals at the input of the automat) onto a set of reactions (signals at the output of the automat). In the process of self-organization, the structure of the automat (and thereby also the matrix of transition probabilities) is transformed, and the degree of self-organization of the system is related to the change of entropy of this matrix. Such a description makes it possible to judge the amount of information obtained by the system during its interaction with the external medium. It is shown that a self-organized system has a structure which enables it to obtain, in an elementary event of interaction with the medium, information greater than log f (where f is the number of reactions at the output of the automat) while a non-self-organized system obtains exactly log f in each elementary event.

An example is considered, and the above proposition is proved on its basis. A criterion of the object of instruction is derived, characterized by the transformation of the matrix that takes place as a result of such instruction.

Various aspects of the application of this model to the description of the formation of human behavior are discussed.

FUNCTIONS OF HUMAN SELF-ADJUSTMENT UNDER COMPLEX DISTURBING INFLUENCES

4

V.A.Berezin, V.M.Vodlozyerov, G.A.Sergeyev, and G.V.Sukhodol'skiy (Leningrad)

Various topics in the study of the stability of "man - automat" systems in which the functional elements include individual human operators are now assuming acute importance. The adaptational power of the human being to assimilate, in a finite time interval, the complex structure of input disturbing signals as well as the extent of his extrapolational functions will determine the effectiveness of self-adjustment regimes of the "man - automat" system. The functions of self-adjustment of the human being are realized by a successive processing of information by the physiological regulators on the micro- and macro-levels. The technique of quantitative analysis of nonlinear transformations of the input information under the regime of self-adjustment has been based on the use of informational characteristics taking account of the relationship, in functional activity, between the elements of the exteroceptive and

Numbers in the margin refer to pagination in the original foreign text.

proprioceptive control circuits (G.A.Sergeyev, 1963).

In the realization of the functions of self-adjustment, the dominant role of the features of the proprioceptive circuit elements is disclosed.

The properties of the extrapolating functions of the human operator, realized by mastery of the stochastic structure of the input influences, are investigated.

The authors show that the difference in the ability of different people to extrapolate may be due to the difference in their psychophysical functions. Data are given on the variability of the dynamic parameters of the self-adjustment functions of the human subject on reaction to nonstationary input signals.

### CONTRIBUTION TO THE QUESTION OF TRANSIENT RESPONSES IN HUMAN SUBJECTS

G.V.Sukhodol'skiy (Leningrad)

All sensorimotor and intellectual acts may be regarded as transient responses. Consequently, the methods of describing transient responses or reaction to sudden impetus developed in the theory of automation and engineering cybernetics are applicable to the study of these acts.

Important characteristics of a transient process are its pattern (or the slope of the curve of the transient function) and the control time. Under /5 given conditions the control time is an index of the speed of reaction of the human subject, while the pattern of the transient response characterizes the pecularities of his mode of action in performing the given act.

In studying the actions of a human operator in one-dimensional tracking of a moving target, the author elucidated three forms of transient response - oscillatory with overshoots, oscillatory without overshoots, and monotonic - and determined the dynamics of their variation during acquisition or learning of the tracking skill (G.V.Sukhodol'skiy, 1963).

A comparison with the results of studies on the methods used by human subjects in solving sensorimotor problems of discrimination and reproduction of stresses (G.V.Sukhodol'skiy, 1960), colors (K.V.Bardin, 1962), or brightness of a luminous field (S.N.Leviyeva, 1963) shows that the same three forms of transient response are observed in these types of human activity, and that the development of habituation is related to a definite pattern of variation in the forms of the transient functions.

The author proposes a special study of the peculiarities of psychic control in various forms of activity by finding the characteristics of the transient responses.

An experimental technique has been developed.

### CONTRIBUTION TO THE QUESTION OF THE FUNCTIONS OF HUMAN BEINGS PARTICIPATING IN THE CONTROL OF NONREGULAR FULL-SCALE SYSTEMS

### D.I.Iordanskiy (Moscow)

Full-scale systems, i.e., systems including human subjects as elements, that consist of subsystems and are not reducible, with respect to the problems to be solved, to an assembly of object-controlling devices, are subdivided into regular and nonregular. The latter solve one-time problems such as, for example, the design of some intricate complex or the building of a nontypical object.

The collective serving a nonregular large system is faced by a number of specific problems. Some of them are discussed in this paper. The author gives structural-functional schemes of organization of the collectives of several of the most typical nonregular full-scale systems. The efficiency of human work in these systems may be considerably improved by the use of data-processing machines and by a rational distribution of functions between man and machine. In this connection, several requirements which must be met by the data-processing machines are formulated by the author.

#### AUTOMATION AND PROGRAMMING IN TELEVISION TRANSMISSION

<u>/6</u>

### V.M.Pokorskiy and A.A.Stepanov (Leningrad)

During the past few years the technical details of producing and transmitting a television program have become highly complicated, because of the great rise in technical and creative possibilities available for television programs. There has been a manifold increase in the number of engineering elements that form the components of modern transmission, making control and monitoring desks far more complicated and increasing the number of control, communication, and signal devices employed. As a result, the problems connected with the control of television transmission have become quite involved. We have repeatedly stated elsewhere in the literature and in our papers read in several scientific and technical conferences that the existing system of television transmission control often makes demands on the operator that are beyond the range of human psychophysiological ability. Technical equipment is beginning to work against man instead of for him. This is convincingly shown by the sharp increase in the number of incidents of so-called "manual" failure in the various television links necessary for transmission.

There has recently been a good deal of criticism of designers who fail to consider the requirements of engineering psychology in laying out the television control desks used by the studio director. If radio engineers would heed the psychologist's findings, the work of the operator at the control desk would be facilitated and the failures would decrease. However, the rapid growth of the Soviet television network and of its facilities renders this solution merely palliative. It is obvious today that questions of control must be resolved on a higher, more active and progressive level, especially in con-

nection with the government decision to build the Great Moscow Television Center in 1967, and make it a model of progress of technique and organization of television.

In finding basic solutions for the questions of television control, consideration must not be confined to the studio control equipment, although this represents the final output stage. Such questions must be settled in all units involved in the transmission process, just as problems of similar type are now being solved in industry branches where the products are turned out on assembly lines. An analysis of the process of television transmission from the viewpoint of engineering psychology suggests the thought that the operators required during transmission in the various units must be freed from the task of manual control of individual primary objects, whose number and rate of operation today already taxes human ability beyond its limit. To increase the personnel in such units is not a solution of the problem. Hence follows the imperative necessity of widespread automation and programming for the control equipment of television transmission.

Introduction of automation and programming into the creative process of television transmission meets two difficulties. First there are a number of purely technical problems: development and manufacture of new equipment, mass production of high-grade television tape recorders, solution of the problem of quality and reliability of equipment, etc.. These engineering-technical problems are difficult, but are entirely concrete and understandable. Secondly, to determine the elements to be automated and programmed is a highly complex task. The point is that television makes use of the creative activity of various types of artists, writers, and journalists. But the field of creation, many people feel, is entirely incompatible with "mechanization". This opinion is quite unfounded: Modern writers have not only abandoned the goose quill, but are eagerly using typewriters and dictating machines in their creative work.

Mechanization, automation, and programming in television transmission should be employed wherever manual work is not an absolute necessity, wherever human labor can be released for purely creative work, wherever the artist will be enabled to work with whole groups of components with extensive use of preassemblage.

It follows that automation and programming must be introduced "from the bottom up", first of all in the service units, for example, in the supply room, in the special lighting-effects shop, in the technical service department where the problem of the operational replacement of failed parts without excessive interference with the schedule of the operator's work is already very acute.

After solving the problems of introduction of advanced technology into the "lower levels" and if high quality and reliable operation of all equipment in television stations is once guaranteed, the next step can be introduction of automation and programming on all levels, up to the central equipment at the disposal of the studio director.

#### ANALYSIS OF THE OPERATOR'S ACTIVITY

### V.P.Zinchenko and N.I.Mayzel (Moscow)

In designing automated control systems, the activity of the human operator must be analyzed. Such an analysis permits predicting efficient activity of the operator in a given system and forms the basis for any correct distribution of functions between man and machine. It is used in formulating instructions for operation of the system, for developing effective training methods, and, /8 finally, for simulating the various forms of operation with the object of their automation.

There exists a wide variety in the type of operators' work in modern control systems. These systems differ in function, structure and critical characteristics (different requirements as to speed, accuracy, stability, etc.). At the present stage of development of engineering psychology, any analyses of the various forms of the operator's work are usually empirical. Their diversity and the absence of any strict classification permits no more than to construct a very generalized model of certain typical operations performed by the human operator in control systems.

Two basic groups of operations can be differentiated:

- 1. Operations of information search. These include: a) perception of incoming data (extracting from the entire set of signals the significant information, detecting deviations from normal operating conditions, etc.), b) processing of the information, i.e., reducing it to a form convenient for solving a service problem (decoding of information, discrimination of a problem situation or a number of problem situations, comparing them, finding the most critical situations, and arranging them in order of importance and urgency for sequence of service).
- 2. <u>Information handling</u>. This group of operations includes: a) problem solution or decision making in problem situations: evaluation of a problem situation, evaluation of available means of control, and selection of those means and methods of action which are most effective in solving a given set of problem situations; b) executing control actions: carrying out the decision developed by means of a definite system of actions or issuing the appropriate instructions.

Two types of relations between information search and information handling are considered: a) information search with immediate handling and b) information search with delayed handling.

As a rule the operator's activity is rigidly defined by the time parameters of the system. The factors determining the efficiency of the operator's work are divided into two groups: 1) objective factors or characteristics of the problem (quantity of information, methods of its presentation, forms of coding, degree of complexity of the algorithm of solution, number and location of the control units, etc.), and 2) subjective factors or characteristics of

the operator (individual peculiarities, training, functional state, etc.).

### CONTRIBUTION TO THE PROBLEM OF WORK OF THE OPERATOR IN SEMI-AUTOMATIC GRADING

/9

V.N.Gorbatenko, G.V.Sukhodol'skiy and V.A.Shcherbakov (Leningrad)

The operator's work in the semi-automatic grading of floating timber was studied.

In this system the task of the operator is to determine visually, on the basis of criteria established by Government standards, the grade of each of the logs delivered by an endless belt and, by depressing a button, to control an automatic sorter which obeys the order to place the log into the proper compartment.

The productivity of the entire system is determined by the speed and accuracy of the grading estimate by the operator, which speed depends in turn on the number of criteria for each grade, the probability of its occurrence, and on the required accuracy, whereas the overall accuracy depends on the ease of discrimination between the criteria for the various grades.

The authors analyzed the discriminability of the criteria on the basis of available literature data and found that the existing criterion scale for estimating grades, developed for hand-grading, was unsuitable under the conditions of the rigid time limit in semi-automatic grading, where a conveyor belt continuously delivers the logs; thus, the system would require reviewing.

The authors attempted to determine the number of logs graded per shift and the percentage of errors (ungraded or improperly graded pieces) for various rates of grading and for a given probability of the combined occurrence of mistakes in determining the criteria and selecting the grade. The rates of grading and the probability of errors were calculated on the basis of a given number of concrete criteria for six grades of floating logs and of the statistics for the corresponding assortment at one of the great roadsteads of the country.

A model of training technique is proposed for training the grading operator. To improve the efficiency of the operation of this system it is recommended that the continuous delivery of lumber be replaced by intermittent delivery effected by the operator himself at an automatic rate.

SIMULATION OF PSYCHIC FUNCTIONS AS A METHOD
OF STUDYING THE MIND

/10

A.A.Bratko (Kiev)

The model system employed in technology and the arts for thousands of

years is rapidly expanding its field of application. Simulation as a method of study has successfully been introduced in physics, biology, philology, and other branches of knowledge. In cybernetics, simulation is the fundamental method of investigating the general laws of control and communication, and consists in creating an isomorphic or isofunctional object and observing its functioning. The construction of analog computers, i.e., the building of a sufficiently complex substratum capable of serving as an analog of such an exceedingly complex dynamic system as the mind will permit the use of simulation in psychology as well.

An analysis of the specific problem of simulation of various natural phenomena, and especially the analysis of models of biological processes and of data processing in the brain, clearly proves the usefulness of the application of analog methods to the study of any form of mental activity.

The use of the analog method in psychology, even at the present level of complexity of analog computers, will permit significant refinement and concretization of physiological data by programming mental processes and verifying the correctness of their definition on the "behavior" of the machine. Simulation will also permit the use of a heuristic approach to the study of mechanisms of psychic activity inaccessible to direct observation, in view of the fact that a model may also be constructed on the basis of hypothetical algorithms, whose correspondence to reality can be verified by comparing the "action" of the machines with the action of a human subject in a corresponding situation.

The application and development of the analog method in psychology will permit establishment of simulated groups of mental processes and, finally, representation of the entire system of psychic activity, which cannot be grasped in its entity, in a simplified comprehensible form. The resultant distinct dynamic picture of the mind will considerably facilitate transition from the study of individual psychic functions to an integral study of the mind.

Use of analog methods enriches psychological research with elements of mathematical methods, permits the introduction of fruitful ideas into the technical sciences which formerly were far removed from this field, and fills in the large gap between psychology and neurophysiology.

SIMULATION OF CERTAIN FEATURES OF MENTAL ACTIVITY ON COMPUTERS

/11

### A.G.Snytkin (Kiev)

Existing forms of machine behavior (meaning computer behavior) are as a rule inflexible, since the processing of data is usually accomplished by a computer on pre-assigned and rigid programs. The "pseudo-independence" of the computer consists in repetition and cyclization of individual parts of the program. Thus, in processing data, the computer projects the input data onto the plane of reactions under rigidly prescribed laws of projection.

The tendency to build cybernetic mechanisms that perform complex forms of human mental activity during their processing makes it necessary to modify both the machine components and the existing forms of computer behavior. The functional trend of designing computers with "higher intellectuality" exactly comprises the goal of imparting new forms of behavior to the machine, i.e., to establish more flexible connections between the input data and the reactions to them.

Simulation of mental processes is possible on large universal digital computers (Univac) with a memory of sufficient capacity and a wide range of instructions.

The first step in establishing these analogs might be the open subroutine system of processing, which observes both the content and the statistical aspect of the input data. The introduction of internal feedback will permit the machine during the processing to modify the data, both at the input and in the memory unit, and thus to accumulate "machine" experience. The open system of processing is, in a sense, a model of passive perception.

The introduction of the "reaction-input" feedback will make it possible to pass from models of passive perception to models of active perception. A block diagram of one of the possible models is presented.

Analogs of mental processes may be objective means for verifying and refining theoretical concepts for psychologists. In these analogs, new types of machine behavior (in program and structural respects) are realized, which will permit complex and specific forms of data processing to be developed.

### MODEL OF AUTOMATIC ADAPTATION TO CHANGING CONDITIONS OF WORK OF THE SYSTEM "MAN-MACHINE"

<u>/12</u>

N.N.Korobov (Kharkov)

The author considers an elementary model of the adaptation of a given system to changing external conditions. A feature of this model is the fact that it performs two functions:

- 1) recognition of the form of the external condition;
- 2) optimum performance of the basic functions (the paper discusses discrimination of a model among background noise).

It is suggested that models of this type are found in the interaction of man and nature (or machine).

The author considers the case in which the input is an additive mixture of signal and noise. The useful signal can be represented by an expansion in series over a complete system of orthonormed functions whose expansion coefficients are random quantities assigned on a set of realizations of environmental conditions, while the interfering signal can be represented by white noise.

The author shows that the optimum characteristic of the system in the optimum case must be determined according to the criterion of the conventional risk of an any-valued function. The characteristics of the optimum system are represented in the form of an expansion in eigenfunctions of the input signal, and the expansion coefficients are determined according to the image of the signal, for which an artificially derived vector  $Q = \{q_i\}$  is used.

The stability of the model is investigated by the direct method of Lyapunov. The author presents the results of a study of the dynamics of a system and the results of simulation on an analog computer and a digital computer.

CONTRIBUTION TO THE PROBLEM OF THE RELIABILITY OF HUMAN SUBJECTS (REGULAR AND RANDOM FAILURES IN OPERATORS WORK)

M.I.Bobneva (Moscow)

The study of questions of reliable human work is of primary importance in developing systems combining the work of technical components and the work of a human operator or system controller. Reliability is an over-all characteristic of human activity. As a working hypothesis, the author defines the re- /13 liability of human work as a man's ability to perform the functions assigned to him under definite working conditions without failure and for a definite time.

In accordance with this definition, the study of the reliability of an operator's work assumes the character of a study of failures in such work. As for the second factor, namely, the working conditions (including the time conditions), the author considers them from the viewpoint of the operator's "resistance to noise".

One of the factors of reliable human work is the dependable operation of the equipment. In this field, the basic problem is the study of the reliability of the operator's reaction to failure of some component of the system and the finding of ways to compensate the interference (for example, development of methods for training an operator to work under unexpected emergency situations).

Another important factor that affects the reliability of human work is the necessity of occasionally working under conditions known to be dangerous, in situations of stress and urgency. The reliability of human work in such situations differs from the reliability of work of an operator of a system of comparable complexity but operating under less urgent conditions. In this field, likewise, an investigation of the methods of compensation is of decisive importance (for example, determination of the factors that eliminate excessive sensation of impending danger, and of methods for dealing with a state of stress).

A study of the methods of compensation will permit exact classification of failures and recognition of the group of actions which should be considered as useful forms of compensation.

In studying the operator's work, the question arises whether providing optimum working conditions and application of effective methods for compensating failures can actually guarantee absolute reliability of human behavior and elimination of all probability of failure in his work. The author answers this question in the negative.

The author distinguishes two types of failures: a) regular and b) random.

Failures with causes that can be discovered and analyzed are classified as regular. This group of failures includes failures resulting from so-called "systematic personal error". (This form of error is discussed in detail in the paper.) All failures of this type may be either eliminated in some way or predicted.

In practice a second type of failure is known. It is often noted that an experienced, healthy, unfatigued, emotionally stable operator, under ordinary normal working conditions, will occasionally exhibit deviations in his work, which must be termed failures and which cannot be explained by any apparent cause. Such failures may be due either to a cause unknown at the time, or to random fluctuations in the man's activity. Such failures are known as random errors or failures.

The author gives examples of random failures of an operator. There are practically no data in existence on such random failures, except for some factors obtained incidentally during investigation of other aspects of an operator's work.

The study of random failures in an operator's work draws attention to the stochastic character of human activity. The author presents several hypotheses on human behavior determined by stochastic laws. She emphasizes in particular the theoretical value of research in this field and the practical value of the discovery of this type of law. In particular, the author defines several ways for "circumventing" the random failures in an operator's work.

CONTRIBUTION TO THE PROBLEM OF RELIABILITY (WORKING CAPACITY) OF HUMAN SUBJECTS IN CONTROL SYSTEMS

K.S.Tochilov
(Leningrad)

From the psychophysiological viewpoint the problem of human reliability reduces to the problem of working capacity. It is well known that human fitness for work follows a phasic course. The phases of fitness for work are determined by the interaction of a series of stimuli (signals) with the functional state of the human organism. This interaction should be considered on two levels, conditioned and unconditioned. This distinction is based on the ability of the organism to adopt the "rhythm" of activity, according to Ukhtomskiy. As applied to systems controlled by human subjects, the term "rhythm" means the adoption of the program of work and the formation of a dynamic stereotype according to Pavlov. The characteristic feature of the dynamic stereotype back—

ground. The latter term encompasses the entire set of stimuli in the given system acting on the human organism.

Transition from the first level to the second constitutes the process of training, reduced somewhat and producing reliability - the stable working capacity of human subjects.

On the conditioned level, the problem of producing great reliability for a maximum time interval is solved by optimum relation between intensity of the stimuli (signal system) and duration of their action. The criterion of in-  $\frac{15}{15}$  tensity of the stimulus is given by the phasic character of its action on the organism, determining the duration of action of the given signal system.

It must be assumed that either a low or a high value of the stimulus is characterized by a shorter duration of stable fitness for work than is a value intermediate between these two. Main emphasis should be on the low intensity of the stimulus at which the state of Ukhtomskiy's operative quiescence sets in. This concept is based on the fact that progress in remote control consists in the constantly increasing use of automation which frees the human subjects from direct action in the system "man - machine". The state of operative quiescence in which man intervenes in the control process only in special emergency cases, against a background of exceptional responsibility, requires maintenance of a high functional level for instant reaction. The prolonged absence of external information-producing stimuli lowers the functional level of the human subject. This requires invention of measures to prevent a performance decrement under such conditions.

### CONTRIBUTION TO THE INVESTIGATION OF THE FUNCTIONAL STATE OF THE HUMAN ORGANISM DURING WORK

### A.V.Dokvadze (Tbilisi)

To investigate the functional state of the nervous and muscular systems in tea pickers under field conditions, portable equipment was designed and approved, for the following compound measurements:

- 1) latent period of motor reaction to the action of compound stimuli of light (red, green, white) and auditory stimuli (click of an instrument);
- 2) accuracy of hand motion;
- 3) tremor of the hands during motion or in static position;
- 4) motions of the wrists at maximum speed.

The equipment comprises a set of instruments mounted in a small box of  $350 \times 250 \times 200$  mm, weighing 5 kg, with its integral power supply in the form of type KBS dry cells.

Of particular interest in this set is the instrument for determining the accuracy of hand movement and tremor. The device determines the number of  $\frac{16}{16}$  errors (contact with a probe) and gives a qualitative characterization of such

errors. The device uses electric counters for counting the number of errors and for computing the total duration of contact between probe and walls of the planchette used to measure the tremors. This combined technique yields data on the functional state of the human organism.

#### ESTIMATING FITNESS FOR WORK WITH CORRECTING TABLES

### S.I.Kopanov (Moscow)

To optimize the relations between the elements in the "man - machine" system, an exact measurement of the human capabilities in data processing is needed. In our work we attempted to study the working fitness of operators (1st series) and of subjects exposed to vestibular stimuli (2nd series). As a criterion for the work fitness of the visual analyzer (analysor) we used the index of the functional ability of the visual analysor to handle the maximum quality of information. The working capacity was determined by means of correction tables proposed by A.A.Genkin, V.I.Medvedev, and M.P.Shek (1963). The tables were composed of Landoldt rings with slits in certain areas. The signals input to the table were equiprobable, uniform, and randomly distributed. The test subjects were instructed to scan all signals in the table (N being the total number of signs), and to discriminate the useful ones. The number of useful signals scanned (n) and the time spent on performing the task (t) were noted. Then, by means of the formula

### $S = \frac{0.5436N - 2.807n}{t}$

we determined the processing power of the visual analysor (s). All results were statistically worked up. The arithmetic means M, the standard deviation  $\sigma$ , the coefficient of calculation accuracy of the mean m, and the security factor t were then computed.

As a result, we found that the number of errors in operators during work increased by comparison with its initial level (by 11.6 - 26.6%) and that the time required to scan the table increased (by 22.8 - 41.4%) while the throughput of the visual analysor declined (by 22.3 - 34.6%). The regularity of 12 these changes was confirmed by the statistical workup of the data. The factor t in most of the calculations was above 3.0. The decline in the functional power of the visual analysor during working time is apparently explained by the appearance of fatigue, owing to the large number of flashing screens and the necessity of constantly following their readings. After work, already after the second hour, the symptoms of visual fatigue disappeared, proving the functional character of the observed changes.

In the second series of experiments we found that the capacity of the subjects varied differently. The throughput of the visual analysor declined in eight subjects (by 7.6 - 14.7%), increased in five (by 4.7 - 11.2%), and remained practically constant in seven. This trend of the changes is obviously due to the varying degree to which the subjects resisted the vestibular stimuli, to the strength of the basic nervous processes, and to the intensity of the

applied stimuli.

It is clear from the data presented that the working capacity of an operator declined more than that of subjects exposed to vestibular stimuli. This is only natural, since in the former case direct fatigue of the visual analysor was involved, while in the latter case the fatigue was indirect.

This trend in the variation of the functional state of the visual analysor must be taken into account in the design of various "man - machine" systems, especially in cases where personnel is subject to vestibular stimuli or fatigue of the visual analysors.

### CONTRIBUTION TO THE STUDY OF THE INFLUENCE OF ACCELERATION AND HYPODYNAMIA ON THE REACTION OF OPERATORS

A.R.Kotovskaya, V.K.Filosofov, N.A.Chekhonadskiy, and V.A.Chichkin (Moscow)

An experimental determination of the dynamic properties of an operator in the "man - machine" system under the influence of external factors is of considerable interest.

The object of the study was to determine the dynamic properties of an operator processing an arbitrary sequence of discrete optical signals under the influence of acceleration.

In this study, the operator's reaction time to an optical signal was determined at random times.

From the data obtained, the relationship of the mathematical expecta- /18 tion to the standard deviation of the operator's reaction time was plotted. The analytic form of the relation of the mathematical expectation of the operator's reaction time to the acceleration can be described by the equation of a straight line.

From the experimental data the authors derive a relation of mathematical expectation of the operator's reaction time to the acceleration and to the relative position of the light indicator in the operator's field of view.

### VARIATIONS IN CORTICAL NEURODYNAMICS DURING INTENSE MENTAL ACTIVITY

G.K.Borisov (Leningrad)

The studies were conducted on train dispatchers who perform intense intellectual work that makes excessive demands on their functions of memory and vigilance, at high intensity, emotivity, extensive workload, and a 12-hour work shift. The data were recorded before and after work, and five times during the

shift itself.

The intensity and amount of work is illustrated by the fact that during a given shift the dispatcher makes over 500 selector and telephone calls (data of the Central Station, October Railroad) and by the fact that the information obtained from the various stations is not merely noted but requires immediate analytic-synthetic action, as a result of which orders and instructions are issued. The variety of information received and the working tools (train selector switch, telephones, charts, timetables, track models, various service logs) demands high stability and ability to shift attention.

A study of the vigilance functions during the course of the working day (Platonov table) showed that the reading time, characterizing the stability of vigilance, became considerably longer after only three hours of work (from 31.6 to 133.5 sec) and then, with minor fluctuations, remained at the high level. Consequently, there was a considerable decline in the stability of vigilance. A task that defines the degree of vigilance shows peaks of increased reading time after the sixth and ninth hour of work (223.3 sec and 213.6 sec as against 175.1 sec before work). No reliable changes were observed during the first three hours of work. The index of transferability of vigilance during the first three hours of work rose from 95.3 to 62.2 sec, and then dropped sharply to 103.7 sec in the sixth hour of work. An analysis of the errors in reading the table points to a considerable increase in number of errors at the end of the sixth hour (2.3) and the ninth hour (2.9) as against the first hour of work (1.04).

A study of the visuomotor reaction shows a substantiated increase in the latent period (from 31.2 to  $40~\sigma$ ), with particularly extensive changes observed from the sixth to the ninth hour and from the ninth to the twelfth hour of work. The latent reaction time after discrimination was likewise increased by an average of 11.3  $\sigma$  at the end of work, most discontinuities in the discrimination being observed by the end of the ninth hour and after completion of the work.

An interpretation of the data reveals various types of reaction to work trouble. In the one case, the functional potentialities of the central nervous system are improved; for example, in dispatcher A, the reading time for the Platonov table in three tests was 42 sec, 52 sec, 2 min 58 sec as against 1 min 19 sec, 1 min 23 sec, 4 min 46 sec observed at the same time but under more quiet working conditions. In dispatcher L the same data were 37 sec, 15 sec, 2 min 28 sec instead of the usual 51 sec, 48 sec, 3 min 19 sec. The number of errors also decreased substantially. In the other case, the functional abilities decline and the number of errors increases substantially, in some cases to 21 (against an average of 2.9 at this time), and the table reading time also increases.

A study of the visuomotor reaction showed a shortening of the latent period after discrimination together with a decrease in the number of discontinuities in such discrimination in the former case, and a lengthening of the latent period after discrimination together with an increase in the discontinuities in discrimination in the latter case.

All the above provides a basis for the following conclusions:

- 1. Under the influence of intense work in dispatchers, there is a considerable deterioration of the vigilance functions, manifesting itself in a decline in stability, transferability, and degree of vigilance.
- 2. The results (Platonov table and study of visuomotor reactions) show a considerable decline in the mobility of the nervous processes, a decrease in lability, and a weakening of discriminatory inhibition.
- 3. An analysis of the fatigue curve shows a decline in certain functions as early as after three hours of work, while a number of other functions reach their maximum values at the sixth to minth hour of work, and certain indices during this period have values that differ only little from those observed after twelve-hour work (transferability of attention, latent period of visuomotor reaction after discrimination, discontinuities in discriminatory inhibition, and so on ).
- 4. Various types of reaction are observed in trouble during work; some subjects show an increase in the functional ability of the central nervous system, while others show a decline.

The data obtained are in complete agreement with earlier studies on /20 railroad dispatchers before and after work (M.G.Babadzhanyan, K.Kiryakov, et al).

DYNAMICS OF VARIATION OF CERTAIN VEGETATIVE FUNCTIONS IN RAILROAD DISPATCHERS AND CORRELATION WITH PSYCHIC MANIFESTATIONS

G.K.Borisov (Leningrad)

The investigations were performed on dispatchers during intense mental work with pronounced emotional stress. (The data were recorded every three hours of work.)

These studies revealed irregularities in the state of the cardiovascular system of the dispatchers, manifesting themselves in a high initial pulse rate (in some cases as high as 90 beats per minute) with a gradual decline by 13.5 beats in the last hour of work, ll.1 beats decrease being observed after six hours of work. This decline was also observed in the systolic blood pressure (from 123.1 to 108.5 mm Hg, i.e., a decline of 14.6 mm Hg) with the diastolic pressure remaining almost unchanged in the range of 75 - 80 mm Hg, after which the pulse pressure decreases, especially during the first three hours of work. The maximum pressure in the temporal artery increased considerably, from 69.5 to 123.5 mm Hg, i.e., by 54 mm Hg. In the first three hours of work it increased by 13.8 mm Hg, but the most rapid rise in the temporal beat pressure was observed in the sixth to the ninth hour of work (21.3 mm Hg increase).

Both pulse and maximum arterial pressure, despite the considerable decline during work, still remained at rather high levels. This can be explained by the high initial values and the great emotional stress, which prevented a further drop in pulse rate and systolic blood pressure. The increase in the max-

imum temporal pressure is closely connected both with the tenseness of the mental effort and with neurological factors. This is confirmed by the following events: When an accident occurred on the line, the dispatcher, Miss 0., had a maximum temporal pressure of 140 mm Hg, a maximum brachial pressure of 130 mm Hg, and a minimum pressure of 100 mm Hg; the dispatcher A. had a maximum /21 temporal pressure of 155, a maximum brachial pressure of 125 and a minimum of 80 mm Hg; conversely, in a normal work shift, Miss 0. had a temporal pressure of 105, a maximum brachial pressure of 115, and a minimum pressure of 90 mm Hg, while A had 80, 110, and 70 mm Hg pressure respectively. This means that, under the influence of nervous stress, the dispatchers exhibit spastic manifestations of the blood vessels of the brain, resulting in a rise in temporal-artery pressure.

Prolonged work and great emotional stress leave their mark not only on the cardiovascular system but also on certain other functions. For example, functional disturbance of the vestibular apparatus occurred (unsteady and ataxic gait, Romberg's sign), with disturbance of equilibrium in 92% of the cases during the last three hours of work. Other symptoms were hand and eyelid tremor, nervous tic, stepped-up diaphoresis, upset of the posture system, changes in handwriting, disturbance of speech coherence, suppression of tendon reflexes, as well as increased nervousness and decreased self-control which manifested itself in pathological reactions during the experiment and to external noise, in shouting when giving orders, excitation of motion, and phenomena of collapse (affectivity).

These psychoneurological phenomena may appear at various times during the work shift, depending on the strain of the work. Some of these symptoms are observed even after three hours of work (disturbance in postural function, tremor of hands and eyelids, shouting when giving orders, etc.) and some only after 12 hours of work (change in handwriting), but most of the impairments (about 78%) occur from the sixth to the ninth hour of work, while the abovedescribed phenomena are strongest and most distinct during precisely this period.

### PROCESSING OF INTERNAL AND EXTERNAL INFORMATION AND HUMAN FATIGUE

Yu.M.Sten'ko (Moscow)

Engineering psychology studies the processing of external information and the issuing of instructions to machines. The processing of external information, however, is inseparably connected with an immense amount of constantly changing internal information.

A study of the fatigue of fishermen during prolonged voyages far from shore showed that the stream of internal information varies with time and increases from the first control system to the fourth (according to N.M.Amosov).

The stream of internal information from the first control system - the

blood - indicates that two periods are involved in maintaining the oxygen content of the blood at a constant level. As the oxygen capacity of the blood decreases, the rate of blood circulation in the lungs decreases in fishermen during the first 60 - 70 days of a voyage, thus improving the oxygenation of the blood; then, after 70 - 80 days at sea, the number of erythrocytes increases sharply, and the blood stream speeds up. However, on the  $90 - 100^{\rm th}$  day, function tests show a decrease in the oxygen content of the blood.

A study of the state of the third control system - the autonomic nervous system or vegetative system - revealed a gradual increase in the tonus of this system. On the  $70-80^{\rm th}$  day, however, the first breakdowns occur, the tonus of the sympathetic nervous system declines in some of the subjects.

A study of the fourth control system - the neurosomatic system - which controls the perception and processing of external information and regulates the motor centers indicated that after 50 - 60 days at sea there occurs an acceleration of the sensorimotor reactions with an increased number of breakdowns of differentiation. After 70 - 80 days a certain adaptation is noted, when the sensorimotor reactions slow down and the breakdowns of differentiation decrease. A certain normalization of other functions, especially of the blood, takes place here.

After 70 - 80 days at sea, the fishermen again show an acceleration of the sensorimotor reactions with an increased number of disinhibitions of differentiation. All this points to an increase in the quantity of "noise" in the control system and indicates the appearance of fatigue in the fishermen. This involves extensive changes in the neuropsychic sphere of the fishermen, primarily in the emotional sphere.

The receipt of positive external information, for instance, that the fishing operations have been completed and the ship is to return, causes a positive emotional upsurge, which eliminates untoward changes of various types in almost all of the systems. The first control system - the cardiovascular system and the blood - is an exception, where many indices reveal more persistent functional changes - development of hypotonia.

Thus, a successive systematic change in prolonged stressful internal information, indicating fatigue of the human subject in the presence of external information causing a positive emotional upsurge, leads to reverse changes in the regulating systems, i.e., first in the higher nervous activity, then in the vegetative nervous system, etc..

On the basis of the results obtained, it is recommended that, to eliminate the initial fatigue of fishermen after 50 - 60 days at sea, an artificial emotional upsurge or extrinsic arousal be produced by having the ship visit any nearby port.

### PROBLEMS OF ENGINEERING PSYCHOLOGY ON SEAGOING SHIPS ON LONG VOYAGES

### P.A.Prosetskiy (Moscow)

During a voyage in various climatic latitudes, the crews of seagoing ships are exposed to the influence of unusual climatic conditions (Arctic, Tropics, Antarctic), and also experience the detrimental effect of a prolonged stay at sea under conditions of partial isolation (monotony of shipboard life, separation from the family, no opportunity for complete relaxation). All this causes complex changes in the neuropsychic sphere of sailors.

In studying the health of sailors on fishing trips in the North Atlantic, on whale hunting expeditions along the coast of Antarctica, or on merchant marine missions in tropical latitudes, we used various psychological methods borrowed from the field of engineering psychology.

To study the speed of sensorimotor reactions, we developed a device which graphically records the test signals and the responses. The stimuli are applied and the response is recorded by the aid of a panel frame equipped with four differently colored bulbs on its four sides. The bulbs light automatically at equal time intervals. The subject's response consists in striking his wrist against one of the four contacts on the inner sides of the frame, the hand being at the center of the frame.

The method is essentially as follows: To each side of the panel frame corresponds a definite color (upper, blue; lower, green; left, yellow; right, red). Wherever, for instance, a blue bulb lights up (bottom, right, or left), the subject must strike only the upper contact. A blow on the contact at the place where the bulb lights (for example, the blue bulb lights at the bottom, and the test subject hits the lower contact) is considered a mistake - a mechanical reaction.

For a "logical" response, the subject must remember the location of the contact corresponding to the lit bulb, no matter where that bulb does light.

This device makes it possible to detect the initial stages of fatigue.

Sailors on long voyages were also tested by special devices that recorded degree and stability of vigilance, amount of logical and mechanical memory, and perception of objects interrelated by various associations (proximity, similarity, or contrast).

In our study we found that, as the time out of port increases, the degree and stability of vigilance decreases, the capacity of memory (especially the / mechanical) declines, the speed of sensorimotor reactions slows down, the level of perception of objects drops, and the number of false responses increases. Irritability and increased fatigue develop. Cases of neurasthenia and psychasthenia are noted.

Psychological methods permit not only to detect any psychic changes in

sailors after prolonged sea voyages, but also to take steps to divert the mind and provide prophylaxis for neuropsychic disorders.

### INTERACTION OF ACCURACY AND STABILITY IN "LIVING SYSTEMS" ON MODELS OF STATIC ADAPTATION

### O.P.Kozerenko (Moscow)

To estimate the individual traits of operators (for selective purposes), we utilized a functional test of static adaptation considered as an "assigned activity" not requiring specific skills (F.D.Gorbov).

The test was to have the subjects maintain a standing position, at first relaxed and then tensely, for a long period of time (30 - 40 min). Several physiological parameters were continuously recorded during this period.

The results of our studies showed that the reactions during the process of static adaptation are not uniform. We may speak of two typical forms of this process:

- 1. The physiological parameters are maintained at some optimum level with periodic smooth deviations toward increase or decrease. The organism displays good stability to "prescribed activity"; and the subjects tolerate the test well.
- 2. The physiological parameters are maintained at the same level (most often, a high level) rather accurately for a long time, without substantial deviations.

The organism shows decreased stability to the "prescribed activity", and sometimes even instability; orthostatic collapse in the test subjects sets in.

Thus the test, being a model of continuous activity, permitted to determine both the stability to "prescribed activity" and the accuracy in maintaining the levels of the recorded physiological indices.

Making use of an important feature of models, namely, analogy, and \( \frac{25}{25} \)
bearing in mind that modern physiology conceives the human organism as a highly complex control system, we may suppose that in the second form of the adaptation process there is an effect closely resembling the well-known conflict, in the theory of automatic control, between accuracy and stability of a controlled system.

DEPENDENCE OF THE ACCURACY OF ACTION ON THE EMOTIONAL STATE

V.L.Marishchuk and N.V.Sysoyev (Leningrad)

The importance of accurate action in the work of an operator is self-

evident. To a certain extent, the concept of reliability of the human subject as an element in the control system is related to this quality. In our opinion, however, engineer psychology has not paid sufficient attention to the fact that, under emotive conditions, certain psychic and motor functions of the human organism undergo substantial modifications.

We studied the ability of human subjects to perform physical exercises, involving only a slight physical burden but requiring rather complex coordination, under conditions of emotional stimulation. In the device used, the subjects performed various coordinated motions of hands and feet, in response to signals given under conditions of distribution and transfer of attention. Recordings were made of the response time, the force applied to the levers, the errors in coordination of the movements and in accuracy of the operations.

In one experimental series we investigated the accuracy of applying the desired force to the pedals of the testing device. It was stipulated that, for correct reaction, the proper pedals had to be depressed with a force not exceeding 3 kg. The subjects, at first in quiet environment, learned the movements and then repeated them without time limitation, for training purposes, after which the control test for speed of operation was made. It was found that these differences, under the conditions of the problems, determined the accuracy with which the required force was applied (Table 1).

TABLE 1

CHANGE IN FORCE APPLIED TO PEDALS DEPENDING ON THE CONDITIONS OF PERFORMING THE MOTION

Conditions of Motion Performance	Value of Quantities Determined, in kg		
011111111111111111111111111111111111111	M	m	sigma
Learning the motion Without time limit With time limit	7.0 10.8 12.8	0.3 0.6 0.6	3.8 6.2 6.2

As shown by the Table, when there was a time limit which, for many of the subjects, constituted a relatively strong emotional factor, the accuracy of the force used in the movements is at its minimum. [This difference is substantiated at a high level of reliability (T = 5.7).] This indicates the substantial influence of emotional stress on the variation in application of the desired force, which is increased by such stress.

It is also very important to note that the number of errors (in accuracy of the operations, in transferability of attention, and in coordination of the movements), was less in tests without time limit than in tests with short time limits. In several cases, the results were paradoxical. The tasks "without time limit" were performed faster than the control tasks "with time limit".

In another study, the subjects were blindfolded and asked to reproduce

from memory, on a hand dynamometer, the prescribed force of 10 kg. The measurements were repeated three times: a) one hour before a parachute jump; b) before getting set in the aircraft; c) after the jump, within 3 - 5 min after striking the ground.

It was found that within one hour before the parachute jump, the error in application of the required force was 1.8 kg, 3.8 kg before getting set in the aircraft and 16.4 kg after the jump. Characteristic in this case are the results of individual deviations, defined by the standard deviation. In the preliminary study sigma was 1.0; before getting set in the aircraft it increased to 2.2, and after the jump it reached 2.9. Thus the scattering of the individual deviations likewise increases with emotional stress.

The next study was devoted to the effect of the emotional state on the accuracy of time-interval discrimination. The subjects, by the aid of a chronometer, reproduced by memory a time interval of 5 sec in ordinary environment; the test was repeated during an aircraft test flight, after the pilot had executed elementary unexpected maneuvers losing 50 - 100 m altitude. Under the emotional stress produced by the stunts, the accuracy in reproducing the time interval of 5 sec decreased by 16.6% on the average. It is of interest that, in a group of athletes who held athletic records and participated in the experiments, the negative variations in estimation of the time interval were smaller (by 5.4%).

### PSYCHOLOGY OF LINOTYPE OPERATOR'S ERRORS AND THEIR REDUCTION

127

A.V.Filippov (Yaroslavl')

It is well known that the percentage of errors committed by linotype operators in typesetting is rather high (the standard is considered to be 5% wrong lines out of the total lines set, but in practice wrong lines run as high as 10 - 15% or more).

The performance of linotype operators decreases sharply because of such errors and the quality of the product is adversely affected (it has been estimated that, on some days, a linotype operator will spend a quarter of his working day in correcting mistakes made during the preceding day).

Prolonged observation of linotype work and experiments have shown that the causative factors for such errors lie in the mental processes or in the inability (at certain moments) of his sensory organs to assimilate the amount of information necessary for high-grade work.

A study of these causative factors makes it possible, without radically redesigning the existing typesetting machines and without interfering with the accepted productive process, to increase the productivity of linotype operators by improving the functioning of the "man" element of the "man - machine" system.

The operator's work on a modern semi-automatic typesetting machine is complex and multi-functional. It is not so much characterized by successive operations but by simultaneous or almost simultaneous performance of a series of operations, which makes excessive demands on the worker's mental abilities.

The industrial process of typesetting on a linotype can be divided into several stages: 1) operator's work with the text of the original; 2) operator's work on the linotype keyboard; 3) makeup and ejection of the slug-line; 4) casting of the line and checking of the finished product.

Mistakes occur most often in the first three stages.

To test the assimilation of the text of the original, the operator was given a series of experimental texts to set, in order to determine the peculiarity of his perception.

We found that, for the operator, the beginning and end of a word are the most significant elements in forming his mental image. The frequent errors of a "static-statistic" type are due to this peculiarity.

It is clear that the components involved in cognitive perception of a word are sometimes inadequate, when the distinctive features of such a word occur exactly in the middle, i.e., in the place that is most difficult to perceive. The inadequacy of the critical components in formation of the cognitive /2 image is the causative factor for the committed error. A successful elimination of such errors requires that the less distinctive components of the perceived object must be made more outstanding.

We determined the word classes with the highest frequency of errors and compiled a dictionary of typical examples. Before setting the type, we then underlined in the copy the words that were difficult to assimilate and instructed the operator to pay special attention to these underlined words. No errors were made in the underlined words throughout the experiment.

The mistakes made on the keyboard resemble those known to psychologists under the terms of anticipation, elision, perseveration, contamination, and transposition. The causative factor here is an overloading of the visual pathways, since work on the type-casting machine is one of the types of activity that is multifunctional in character but limited to a single sensory tract for reception of information from the work objects. Successful prevention of such mistakes requires broadening of the sensory "input" of information.

For example, one might replace the visual control of the keyboard work by tactual control. Such cases of substitution are known in technology (levers of cranes, etc.). However, until now replacement of vision by touch always involved strong stimuli. In our case, in contrast, the stimuli were near their threshold value, and the time for their recognition was measured in hundredths of a second.

Our study proved that such substitution is possible. On the keys of the linotype, we gradually replaced the graphic representations of the letters by

affixed convex figures corresponding to the shape of the particular letter. Today our linetype operators work on a keyboard that is fully adapted for touch typesetting. Preliminary results indicate that their linetype work has definitely improved.

#### ENGINEERING PSYCHOLOGY AND INDUSTRIAL ESTHETICS

### P.A.Kudin (Leningrad)

In problems that involve matching of the design features of a given machine to the characteristics of the human operator, an important place is occupied by industrial esthetics, which is closely related to engineering psychology.

The development of the principles of industrial esthetics requires psychological analysis of the structure of the activity of the human operator controlling the machines. At the same time, the methods of industrial esthetics can solve many problems of engineering psychology.

Esthetics of technical form includes esthetics of machines, machine tools, apparatus, instruments, cutting tools, means of transportation, and the work place.

The means of expression of industrial esthetics are:

artistic form; functional light; functional color; spatial composition.

Esthetics of technical form is determined by the degree in which the order of elements, mass, materials, color, and light is presented. The laws assuring the esthetic effect are objective and inherent in various fields of artistic creativity.

Light and color constitute the atmosphere of production. Illumination and the color decision can disclose the function of the various elements of equipment, attract the operator's attention, create "psychological points of impact", increase activity during monotonous work, neutralize feelings of heat or cold, remove the impression of burden, etc..

Spatial composition of technical objects is characterized by the following factors: form adapted to the functional purpose correlated with the environment; in proportion to the size of the operator's body; proper rhythm, proportions, etc..

The means of expression for industrial esthetics may influence the working activity of the operator and improve his efficiency. By making use of these means, we can create an emotionally favorable atmosphere, facilitate the reception of information, improve concentration and transferability of attention,

increase the speed and accuracy of perception, enhance the economy of control motions, improve their spatial pattern and accuracy, and eliminate stress or monotony in the operator's work.

The artistic form of technical objects is the product of the combined effort of engineers, psychologists, and artists and requires the synthesis of technological, psychological and esthetic knowledge.

The principles of logic of designing, engineering psychology, and industrial esthetics must be harmoniously welded into an indivisible whole.

#### ENGINEERING PSYCHOLOGY AND INDUSTRIAL HYGIENE

Ya. Neyshtadt (Moscow)

In work hygiene, the study of the workingman is combined with a study of his external environment. Industrial hygiene is intertwined with physiology, on which work psychology is also based. The link between engineering psychology and work hygiene is primarily formed by unity of the physiological methods used in both disciplines.

The hygienic conditions of the environment affect the character of the neuropsychic activity of the workingman: the degree of illumination produces the proper "adjustment" of the visual receptor, the loudness level in phons predetermines the load on the auditory analyzer, etc.

The increasing speed of the productive processes, so characteristic of modern technology, the increase in the number of signals conveying information on the productive process, and the like, demand a deepening of the psychological analysis of work performance. As a result, the psychophysiological component is intensified in the developed hygienic investigation.

The new technical level of modern production and the tendency of technology to expand further make it mandatory to link the progress in the development of technology to the science of hygienics by extensive use of cybernetic methods and processes in any hygienic studies. This likewise correlates the hygiene and physiology of work with engineering psychology.

The significance of engineering psychology for hygiene will be clear from an analysis of several hygienic studies performed at the Central Research Laboratory for Hygiene of Water Transportation, including the subjects:

- a) "Labor conditions with combination of traffic on ships" (complication of the group of operations connected with vigilance, etc. when the occupational pattern is changed);
- b) "Hygienic rationalization of labor in stevedore teams" (alternation of different productive functions as the principle of active rest);
- c) "Determination of permissible duration of voyages in the high North" (significance of neuropsychic components in the production

/30

cycle);

d) "Visuomotor functions in steering ships on underwater hydrofoils", etc.

The strengthening of the relations between engineering psychology and work hygiene can proceed in various ways. The factors of the productive medium, reduced to hygienically optimum parameters, will produce the conditions necessary for the most complete and perfect development of the psychophysiological aspects of the human subject. The multilateral development of person- /31 ality will encourage the productive activity of the new society.

It has already become necessary, today, to coordinate the work of psychologists and industrial hygienists in the specialized work directed toward solution of these problems.

### CONTRIBUTION TO THE QUESTION OF THE RATIONAL LOCATION OF INDICATORS AND CONTROLS ON CONTROL DESKS

# R.M.Mansurov (Leningrad)

The development of remote-control systems involves an extremely rapid increase in the number of indicators feeding information to the operator and the number of controls he must manipulate.

In this connection, the question of a rational organization of the sensory and motor centers of the operator is becoming increasingly acute and, even more so, the problem of arranging the indicators and controls on the control desk so as to maximize speed, accuracy, and reliability of the operator's performance under the given conditions.

Numerous anthropometric, physiological, and psychological studies have shown that the several regions of the sensory and motor centers are by no means equivalent in "convenience" for the human subject (Barnes, Fitts, Chapanis, McCormick, Pakhomov, Izmail'tsev and others).

Earlier work on engineering psychology has shown that the position of the indicators and controls on the control desk must correspond to their "link value", determined according to their importance for the problems of control and the frequency of use. The elements of the control desk with the highest "link value" must be located in the optimum zones of the sensory and motor regions. Later, for determination of the link value of the elements of the control desk, the sequence of their use also began to be taken into account. This was the first step in the transition from the static to the dynamic principle of studying control desks.

In developing and designing control desks, the most important problem is to find the factors that determine the importance, frequency, and sequence of use of all their elements.

This problem cannot be solved without analyzing the structure and dynamics of the entire control system as a whole, and of the environment in which it operates. Thus, the sequence in which the indicators and controls are used is determined by the sequence of interaction between the units and blocks of the system, resulting from the structural scheme of the system and the features of the technical devices used in it. In this case, we may take account of the /32 character of the linkages between the elements of the system (whether strictly determining or of the probability type). The frequency of use of the controldesk elements is determined by the probability of some particular situation arising in the medium in which the system functions, etc.

With such an approach, the conduct of engineering psychology studies requires extensive use of data and applications of the methods of system technology.

### PRINCIPLES OF EVALUATION OF A WORK STATION ACCORDING TO ENGINEERING PSYCHOLOGY

L.V.Kuchevskaya (Moscow)

Based on the principles of analysis of the activity of the human operator (cf. abstract of paper by V.P.Zinchenko and N.I.Mayzel'), we distinguish two types of service: direct service, performed immediately following the information search, and delayed service, performed after arranging in order the control objects requiring service.

The algorithms of the operator's work are classified in accordance with the types of service, and to realize them various requirements must be met by the design of the work station (location of the indicators and controls), by the arrangement of the controls on the control desks (according to frequency and sequence of their use and to anthropometric standards), and by the characteristics of the controls themselves (grouping, color coding, shape coding, etc.).

#### ARTIFICIAL LIGHTING OF THE OPERATOR WORK STATION

L.N.Meyer and A.G.Tishchenko (Moscow)

An operator's fitness for work is, to a considerable extent, determined by the color and intensity of the light at his work place. The object of this study was to determine the optimum artificial lighting conditions (spectral composition and level of illumination), which would at the same time ensure both high visual acuity and a sufficiently high level of sensitivity to light. Such requirements are often encountered in aviation.

The author studied the relation of the selected functions, acuity of vision and light sensitivity, discriminated by the center and periphery of the retina, and the color and brightness of the field of adaptation.

The resultant data showed that light of two colors was most efficient: yellow light, from sodium lamps or a combination of color filters ZS-7 and OS-13; and white light from an incandescent lamp at a color temperature of 2854°K. The use of these colors at a brightness level or intensity luminance of 1 nit ensures a visual acuity of over 1.0 at an adequate level of light sensitivity. Taking account of the effect of acceleration and vibration, according to literature data, the brightness range should be extended to 0.3 - 33 - 127 nit, according to the specific problems and conditions.

#### TRAINING AND SELECTION OF OPERATORS. TRAINING TO SOLVE CONTROL PROBLEMS

#### Ye.V.Voloshinova and G.K.Tvilineva

In many modern automatic control systems the human operator continues to play the role of the decisive element. In this connection, we must investigate the complex interrelations established between the human operator and the automatic machine during their combined work, and to elucidate the physiological mechanisms of activity of the brain during control.

In technology, we meet problems of controlling objects whose normal operation is due to a certain constant value of the controlled output quantity. The control of such objects consists in so actuating the controls of some mechanism that the controlled quantity is brought to the prescribed level and held there.

In our studies we built a model of a system for controlling such objects. We developed a special experimental environment consisting of a computer, a switchboard, and a control desk. An electronic model of the controlled object was set up on the computer. The control lever (control element) and several measuring instruments were located on the control desk.

During the experiments we took electroencephalograms of the occipital region and the rolandic area of the brain, as well as electromyograms of the lower jaw, and also recorded the galvanic skin resistance.

The process of training was studied in the control of objects of vari- /34 ous degrees of complexity. The controlled objects were described by differential equations of the first, second, third, and fourth orders. Certain processes of selecting and screening of information during training, as well as certain physiological mechanisms of brain activity during the teaching of control, were studied.

The authors also investigated the possibilities of controlling an object at various speeds of the processes in the object (various rates of conversion of the input quantity to the output quantity), and found the optimum speeds minimizing the time required for an operator to solve the control problem.

### SOME METHODS OF IMPROVING THE EFFECTIVENESS OF TEACHING THE SEVERAL ELEMENTS OF OPERATOR WORK

V.A.Bodrov (Leningrad)

The purpose of the study was to formulate a psychophysiological evaluation of the training of specialist operators to work on a discrete system of automatic control, and to develop several methods of improving the effectiveness of this training.

The results of the evaluation of the training process for specialists by working tests and psychophysiological methods indicated that the level of their training to perform the tasks under the conditions of actual work was inadequate.

To improve the effectiveness of training for specialists, the authors propose to develop the basic elements of the operations characteristic of any form of an operator's action on control apparatus, by the aid of special training devices and form boards. These devices permitted the development of orientation patterns as to the relative positions of indicators and manipulators, taking readings and setting up of data in the machine, prolonged motor activity with the manipulators, and solution of logical problems.

An experimental check of the recommendations showed that the subjects given a training course on the proposed trainers, obtained higher marks on the working tests and psychophysiological studies than subjects trained by conventional methods. In particular, their instrument reading time was 21% shorter, and they made 23% fewer errors. During the training, the experimental group showed a more marked improvement in accuracy and coordination of motor activities (according to RDO and tremor measurements) than the control group, as well as greater increase in the speed of data processing (according to Landolt-ring tables), greater improvement in the development and reorganization of mental set (according to the "digit-symbol substitution test"), improved stability of vigilance (according to the "broken-line test") and ability to operate with spatial concepts (according to the "compass" test).

The pedagogical observations also indicate that supplementary training, with the use of special devices to develop individual elements of the working process, considerably improved the training level of specialists in operation.

STUDY OF THE EFFECT OF NONSPECIFIC TRAINING ON THE ABILITY TO PROCESS INFORMATION UNDER SPECIAL CONDITIONS

V.M.Zatsiorskiy and O.P.Frolov (Moscow)

The speed of data processing by a human subject in a given situation depends on his individual traits, and especially on the degree of training for the work in the given system. In this study, an attempt was made to elucidate the influence of nonspecific training on an operator's ability to process in-

formation under certain conditions. In other words, we investigated the transfer of training with respect to the processing of information. The transfer of training can, in principle, be observed by replacing the training conditions by test conditions, and modifying:

- 1) the signal complex;
- 2) the effector complex;
- 3) both signal and effector complexes.

This paper relates only to the first case (change in the signal group).

The athletic activity of boxers was taken as a model of nonspecific training. The use of athletes as study objects has certain advantages: constant training for many years, strict selective system making it possible to single out the strongest candidates, etc.

The experimental situation was specified as follows: The subjects were instructed to react by various boxing maneuvers to the lighting of bulbs each of which, by color and position, corresponded to a definite pass. The latent reaction time was recorded. Two series of experiments were run, with equiprobable and nonequiprobable signals, in the range from 0 to 3 hits.

In accordance with "Hick's law", a linear dependence of the reaction time on the average amount of information per signal was observed. The regression coefficient, calculated by the method of least squares and correlating the average amount of information per signal with the reaction time, decreased as the subject acquired greater skill. The advantage of highly qualified athletes was particularly distinct in the range from 1.5 to 3 hits.

The obtained data are interpreted as a confirmation of the hypothesis that training is transferred in proportion to the ability of processing information.

#### SPECIALIZED PHYSICAL TRAINING OF A MACHINE OPERATOR

T.T.Dzhamgarov and V.L.Marishchuk (Leningrad)

Neither the development of mechanical equipment nor the existence of electronic computers have in the slightest degree diminished the role of the human operator in controlling such equipment. The human subject always has been and still is the most important link in the system of controlling the machine, to say nothing of programming and planning. At the same time, engineering psychology must not only study the adaptation of the machine to the functional abilities of man but also solve a no less vital problem, that of active improvement of those functions of the operator which are most important for the successful control of some particular machine.

The authors (in collaboration with A.S.Bulatov and N.L.Testov) investigated the relation between successful mastery of an aircraft pilot's task and the state of physical preparation, in various respects, of student pilots. We found that, in the absolute majority of cases, test subjects with excellent and

multilateral physical training made excellent marks in flight preparation. At the same time, in many cases, some occasional deficiency in the traits important for flight training prevented otherwise good athletes, and even exceptionally qualified athletes, from learning how to fly (A.V.Korobkov and V.L.Marishchuk, 1960). In this connection, we find justification for the idea of differential training with special emphasis on improvement of specific flying traits, which may also be interpreted with respect to training for other operator's jobs.

In one experimental series (in collaboration with N.V.Sysovev), in a /37 special study of subjects preparing for training on the Zh-18 sports trainer, we found that 72 of them exhibited individual inadequacies in certain physical and psychological traits that are important in flying an aircraft. A total of 45 subjects of this group were used for experimental physical training to specifically improve the traits in which they had been found deficient. These were as follows: groups to improve emotional stability (15 subjects); groups to improve the functions of vigilance and speed of action (15 subjects); groups to improve motor coordination and accuracy (15 subjects); 27 subjects were used as control group. Regular training enabled the subjects in the experimental group (45 subjects) to overcome these faults to a large extent and to reach the average level of the other test subjects in these traits. The favorable changes were statistically substantiated. In the control group (by means of general and special measures), we likewise noted some improvement in the traits under investigation, but the improvement was less marked. When actual flights began, the subjects who had been in the experimental group were far more successful in mastering the technique of piloting, and on the average needed 26.7% less actual flight training time (and accordingly also cost less to train) than the control group. Moreover, eight subjects of the control group were dropped from the course for failure in flight (as not meeting the required reliability of control), but only one subject from the experimental group.

These data indicate the expedience and high effectiveness of physical training, specifically directed toward improvement of certain physical and psychological traits of particular importance in the control of a given mechanism.

### PRINCIPAL ELEMENTS IN OPERATOR TRAINING TO READ INDICATOR PANELS

N.F.Fedotova (Leningrad)

Training an operator to take readings on an indicator panel is a complex process that includes the formation and reorganization of a number of sensory, motor, and intellectual patterns.

Ten-day training in indicator-panel reading considerably decreases the number of errors committed by the trainees. During the training period, the \( \frac{38}{28} \) number of errors decreased by a factor of 3.5. The percentage of correct readings increased during this period from 77.2 (in the first test) to 93.8 (in the tenth test).

The character of the instruction is of substantial importance for the success of training. When detailed instruction was given and the design features of the material were explained, the proportion of correct readings increased from 81.2% in the first experiment to 96.4% in the tenth. Shorter instructions, without covering the design principles of the material and with only practical guidance for taking the readings, were quantitatively less effective.

The fact that the training results were better when instructions were given indicates that it is essential in training an operator to subject him to such preliminary theoretical preparation as will establish the correlation between individual information elements and will permit to some extent to predict their variation.

The changes in the quantitative data during the training involve a long and complex process of formation of new habits and reorganization of old ones, meaning that the psychological content of the training is responsible for these changes.

According to our results, the following components can be distinguished in the process of operator training:

- 1. Formation of the habit of cognition of numerals in a new script. One of the difficult factors of this process is the discrimination of digits of similar structure: 1 and 7; 5 and 6; 3 and 9; etc.
- 2. Formation of operative memory, which is a prerequisite for identification and discrimination of digit symbols.
- 3. Formation of the mental set of evaluating the probabilities of change of the readings, which can be obtained by reconstruction of the a priori evaluation of these events as equiprobable.
- 4. Formation of the habit of distribution and transfer of attention, which are the operator's most essential working skill.

During reading, two forms of organization of awareness are possible: a) successive transfer of awareness from one observed object to the next; b) distribution of awareness over several objects requiring perception as an integral group.

The necessary condition for distribution of awareness is a rational arrangement of the signals on the panel, with those of similar meaning and similar probability of change grouped together.

During training, a certain definite sequence of transfer of awareness is developed. In our experiments this sequence was manifested as the instrument-reading route. It may be assumed that the changes in the effectiveness of training at various stages are related to the reorganization of these routes.

5. Formation of the feel of rhythmicity in the program, which helped /39 to successfully read a large number of regular simultaneous changes. Under our test conditions, a large number of simultaneous changes had to be read off,

leading to a highly stressed process of excitation. According to the law of induction, this process was replaced by inhibition, which was the cause of mistakes in reading the subsequent frames of the program.

### SIGNIFICANCE OF CERTAIN PSYCHOPHYSIOLOGICAL INDICES FOR INDUSTRIAL SELECTION

# V.A.Bobrov and G.M.Zarakovskiy (Leningrad)

To develop psychophysiological criteria for the professional selection of operator specialists, the authors studied the relationship between the quality of work at control desks during training and certain physiological and psychological traits.

It was found that subjects with a higher level of preparation for work at control desks had not only better marks in fitness for work for the individual elements of the process (according to the results of work tests), but also had higher marks characterizing the accuracy and coordination of motor activity, speed of processing information, amount and transfer of awareness, and capacity for spatial orientation.

To select the psychophysiological techniques for evaluating the most important properties and traits of the operator's organism, necessary for successful performance of the principal work tasks, we investigated the correlation between the results of a combined evaluation of the level of preparation for the operator's job (data given by the instructor-teaching staff after completion of the process of teaching and training of specialists) and the results of special tests.

We found that there is a rather close correlation between the teacher's estimate and various indices of work tests such as the speed of prolonged rotation of an instrument dial (correlation coefficient  $\rho = 0.459$ ), the dial reading time and the time for setting up data in the instrument ( $\rho = 0.468$ ), the number of errors in taking the readings ( $\rho = 0.457$ ), the "coefficient of success" in the "compass" method ( $\rho = 0.475$ ), the number of digits reproduced in the "digit-memory" test ( $\rho = 0.429$ ), the mean value of the difference in productivity during separate time intervals in the "addition and carryover" test ( $\rho = 0.466$ ); the time to perform an assignment in the "digit selection and  $\frac{140}{120}$  carryover" test ( $\rho = 0.676$ ); index of rate of information processing in the correction test "Landoldt ring tables" ( $\rho = 0.423$ ); index of total deviation from zero in the RDO test ( $\rho = 0.440$ ) and reaction time to tasks of increasing complexity ( $\rho = 0.500$ ).

The effectiveness of the above industrial selection tests was verified in a special experiment. The results were positive.

#### THE INDIVIDUAL AND THE GROUP IN EXPERIMENTAL GROUP PSYCHOLOGY

F.D.Gorbov (Moscow)

The study of group operative activity, undertaken for a comparative evaluation of the effectiveness of the work of several groups, simultaneously constitutes an effective means for determining the individual psychological traits of a given operator.

The study was based on short-term experiments which used analogs of the operator's activity in the control of the controlled objects, and also on long-term experiments resembling actual operating conditions.

This layout of the investigation required a number of restrictions and was distinguished by the following characteristic features:

- 1. The experiments consisted of continuous activity, with obligatory sequence of operations following a pre-assigned program.
- 2. A definite time limit was set.
- 3. The results were obtained by averaging (instrument indicators).

The activity was correlated with tasks of graded difficulty, ensured by the introduction of various mutual correlation coefficients. For this, temporary substitution of one of the members of the group by another from the collective of subjects was used.

With this layout of the investigation and thanks to the development of our own original techniques and methods (homeostat: F.D.Gorbov, M.A.Novikov, Ye.S. Ventsel', I.Ye.Tsybulevskiy, and M.I.Klevtsov; paired-word test and tests with "leader"; M.A.Novikov; "time-sequence or relay test": V.T.Lebedeva; group electrography: F.D.Gorbov, V.I.Myasnikov and I.P.Lebedeva), it became possible to estimate the effectiveness of the group activity according to the criteria of trainability in "organization", the presence of "authoritarian" and "parity" tactics, and also to map out the possibility, in selecting and training operators, for joint and interrelated work in successive and simultaneous func- /42 tional units.

The results permit us to speak of the variability of certain time-dependent characteristics used for judging the individual traits of a human subject. In particular, we established the variability of indices such as "personal reaction time" in competitive situations (M.A.Novikov). These data are in agreement with the data of individual studies on the interrelation of stability and accuracy obtained on models of static adaptation (O.P.Kozerenko).

The space-time approach to joint activity permits the concept of "body scheme" to be supplemented by the concept of "aureole" (conventionally), which

expresses the spatial requirement of an individual in group activity and permits us to speak of the optimum spatial and structural arrangement of a group.

When artificial obstacles to group work are established, certain pathological states of the "frontal syndrome" can be simulated.

On the whole, it can be noted that interrelated group activity on a common task discloses the individual traits of the group members with maximum distinctness in precisely those cases where the level of mutual activity is highest.

#### INDIVIDUAL DIFFERENCES IN GROUP ACTIVITY

M.A.Novikov (Moscow)

The integral approach to the study of groups of operators working independently, but interconnected by the necessity of close interaction in performing an interdependent activity, has shown a certain onesidedness of the results of determining the typological features by conventional methods, obtained without taking into consideration the game aspect characteristic of group activity.

This onesidedness showed particularly in the impossibility of predicting the behavior of operators in any particular group and of predicting the effect-iveness of the activity of the group as a whole. For these purposes, we made use of the integrative techniques developed in the laboratory headed by F.D. Gorbov:

Paired-word test (M.A.Novikov, 1961); Homeostatic method (F.D.Gorbov, M.A.Novikov, M.I.Klevtsov and I.Ye. Tsibulevskiy, 1962).

The paired-word test, based on the verbal ("associative") test, con- /4 sists in an assigned verbal activity in which the subjects mutually are represented as noise. The competitive conditions represented in the test in the extended form, create the conditions for emotionervous stress. In analyzing the results of the test, the latency periods of verbal reactions are measured (determined are: mathematical expectation, dispersion or variance, and normed index of reaction stability) and the character of the verbal reactions ("compulsive" responses) as well as the vegetative reactions are determined.

The homeostatic test consists in recording the activity of the operator required to eliminate the deviation of a pointer from zero position. A feature of the "homeostat" apparatus is that the operator's desks are interconnected so that personal success does not mean solution of the group problem. The group solution of the problems, of various degrees of difficulty, is possible only with the coordinated work of the operators. Work on the homeostat tester is a type of cooperative problem from the viewpoint of the theory of games.

Our studies, using young healthy subjects of 21 to 23 years of age, on the paired-word test (40 subjects in various combinations of pairs) and the homeostatic method (30 subjects in various combinations of three subjects each),

showed that the results depended on the tactics of the group and that the other participants in the experiment were not indifferent to the individual subjects.

The speed of the responses (paired-word test) was used for differentiating slow and fast operators, and their resistance to noise (fluctuation in variance of the latency period and "compulsive" reactions) was used for separating stable from unstable operators. The tactics of running a group test were also disclosed: rivalry and domineering, in which the subjects mutually adapt their verbal response reactions.

With the homeostatic method we found varying values of the correlation coefficient and of the slope of the regression curve, respectively determining the stability and activity of the operator's work.

Positive values of the coefficients mean that the tactics of the "dispatcher" ("leader") of the group are being followed by the single operator, indicating good motility and equilibrium of the basic nervous processes.

High negative values of the coefficients reflect inertness of the nervous processes, while low negative values reveal relative weakness of the process of internal inhibition, causing irrational and impulsive behavior.

This is also substantiated by the qualitative criteria of the operator's activity on the homeostat tester, found by plotting graphs in phase space.

Wide spacing of the spiral formed by the motion of the representative point along the coordinate on which the position of the control handle is plotted characterizes inertness of the excitatory process, etc.

144

The cardinal concepts are segregated for study: strategy of the group and tactics of the individual operators, determined by the personality traits of the subject and by the interaction of participants with various typological traits in interdependent group activity.

The use of integrated techniques in determining personality traits makes it possible to study the subject under conditions close to actual working or production conditions, taking account of the reciprocal influence of the operators taking part in the experiments.

### THE "TIME SEQUENCE TEST" AS A MODEL OF EXPECTATION IN GROUP ACTIVITY

V.T.Lebedeva (Moscow)

The joint activity of operators controlling complex systems requires detailed study, which becomes promising when simulation is used (F.D.Gorbov).

Such simulation should take account of emotional stress, which often affects the accuracy of operation in individual and group activity.

The time sequence or relay test consists in a joint determination of a prescribed time interval by two operators, one commencing the reckoning and the other completing it. The task was, for the two subjects together, to determine a twenty-second time interval, each in turn estimating a ten-second interval from memory and attempting to obtain the total of twenty seconds. The signal that the interval had been completed by one of the subjects was the signal for the other to begin. The operators alternated as leaders of the "trial".

The experimental study was based on the model of alternate performance by two persons of the same operation, including the factor of expectation in its imagional representation or performance.

The basic characteristic of such activity, or of its analog, is the successive alternation of operations, in turn implying alternation of the state of expectation and still more intensifying the competitive character of the study.

Electroencephalograms (EEG), galvanic-skin resistance (GSR), and electromyograms were recorded during the test to check the beginning and end of the <u>/45</u> count simultaneously in both operators.

This test made it possible: 1) to select, from several pairs of operators, the most successful pair in "relay counting" in the highest group accuracy of the result; 2) to evaluate the individual accuracy of the count as a sign of neuropsychic stability; 3) to confirm by EEG the state of expectation (from the "arousal" reactions); 4) to find, in the training variant, the possibility of developing a new quality of group activity termed arbitrarily by us "group sense of time".

### ELECTROGRAPHIC STUDY OF THE EFFECTIVENESS OF PERCEPTION OF A SIGNAL IN A COMPETITIVE SITUATION

# V.I.Myasnikov and I.P.Lebedeva (Moscow)

A model of the activity of two operators is considered. The activity is characterized by the prolonged stay of both operators under observational conditions, with the requirement of rapid simultaneous reaction to an incoming "alarm" signal (in random sequence). The reaction is doubled. The doubling of the reaction, i.e., its parallel performance by both operators, is introduced for "reliability".

To evaluate the effectiveness of the perception of the signal, we used the technique of determining the speed of a motor response in the competitive test variant with joint activity of both operators. Such group activity permits simulating an emotionally saturated situation under experimental conditions.

The functional abilities of the operators were evaluated in various manners, based on the simultaneous recording of a number of electrophysiological indices: biopotentials of the brain, biocurrents of the muscles of the deep flexor of the fingers of the right wrist, and galvanic skin resistance.

The electrographic study of the effectiveness of perception, under the direction of F.D.Gorbov, showed that the individual psychological features of the operators (resistance to noise, speed of reaction, accuracy and coordination of movements, etc.) are characteristic for each of these operators in individual activity and are manifested with particular clearness under the conditions of a competitive situation.

The latency period of the response reaction, as an objective index of  $\frac{46}{46}$  the effectiveness of perception, was found to be directly correlated with the degree of the orienting reaction (at the instant of the signal).

It was found that the latency period of the motor reaction, recorded in the individual variant, was shorter when the same test was performed in a competitive experimental situation. The response was accompanied by a pronounced electric skin reflex without tendency to shorten when the signal was repeated.

PSYCHOPHYSIOLOGICAL REACTIONS IN OPERATORS UNDER THE ACTION OF A VIBRATION STIMULUS AND UNDER CONDITIONS OF ISOLATION

A.A.Koreshkov (Moscow)

In this study we considered the methods and data of an investigation of the state of the cardiovascular system of operators under the influence of a vibration stimulus and under the conditions of prolonged isolation, in which the effect of solitude and the features of the cooperation of a group of subjects under the same conditions were studied (F.D.Gorbov).

The studies as to the effect of vibration on certain psychological and physiological functions showed that all operators exposed to vibration, within certain limits, very rapidly developed adaptation, which subsequently remained stable. During this adaptation process, we noted symptoms of sinus arrythmia, which were transitory and not very pronounced.

The individual variation in the effect of vibration on the human organism is so considerable that scientific dictionaries for specialists even contain the term "vibration resistance". "Vibration-nonresistant" subjects manifest a pronounced intolerance for these influences (marked vegetative symptoms of physiological discomfort: pallor, excessive diaphoresis, etc.; unpleasant subjective sensations, mainly of pain, and general psychic depression).

The precise opposite of this group are persons with exceptionally high vibration resistance.

Confinement in a small room exerts a specific influence on the organism, which is intensified if the subject is in solitude.

During stay in such an isolation room, electrocardiograms (EGG) were <u>/47</u> made at specified intervals, and the pulse rate was taken during the entire period. The EGG showed normal cardiac function under these conditions. Study

of the patterns of mutual habituation and coordination of a group of operators during prolonged isolation is of great current interest. Small groups of operators participated in our studies and were kept for long periods of time in specially equipped sealed chambers.

Alternation of activity and rest of the subjects was prescribed by special instructions. Throughout the entire period of the study, the physiological and psychological reactions of the subjects to the conditions in isolation chambers were recorded. The conclusion can be drawn from the results that prolonged stay of a group of subjects under conditions of isolation in a small room does not interfere with the interrelations of the participants and that, in fact, the special features of these relationships are determined primarily by the moral qualities of personality of the group members and by the degree of synchronization of the tempo of their psychic activity (F.D.Gorbov and M.A.Novikov). No pronounced deviations in physiological functions, especially in the cardiovascular system, were observed in any member of the group.

APPLICATION OF THE METHODS OF THE THEORY OF MASS SERVICING
TO THE PROBLEMS OF ENGINEERING PSYCHOLOGY

L.V.Fatkin (Moscow)

On the basis of the theoretical assumptions contained in a paper by V.P. Zinchenko and N.I.Mayzel' and concerning the activity of an operator, a discussion is given on the possibilities and especially on the limits of applicability of the methods of the theory of mass service to an analysis of the operator activity in a complex automatic control system (ACS).

The information input system in the ACS under study consisted of a series of units, all of the same type, on which a limited set of states of the individual single-type components of the system was indexed. The decisions of the operator, taken for each of these states, were fed into the ACS by coded instructions whose set was likewise limited, and the selection and dispatch of the command was accomplished by means of pushbutton selector switches. A limited time was prescribed for making the decision for each of the states, and the probability of a simultaneous change of state of all units of the system was kept small (conditional).

A model of such a working situation, in which the operator must search for information in an information domain established by a representing device or simulator and then turn to the data-input unit of the ACS, may be represented by a system of mass service with a Poisson traffic of calls on a single service unit with provision for formation of turns (i.e., without failures of service).

The methods of the theory of mass service were used to derive formulas for a given type of service system, reflecting the dependence of the mean waiting time and the mean duration of a turn on the number of single-type blocks served by the operator, under two assumptions relative to the servicing time of one call: 1) the servicing time is distributed according to an exponential-decay law and 2) the servicing time per call is constant. By the aid of these /50 formulas we plotted the relations permitting us to find, for a specified average servicing time and a specified number of units served, the mean duration of a turn and the mean waiting time for service.

On the basis of the mathematical and engineering psychological analysis of a given concrete problem, we made recommendations for rearrangement of the operative work conditions.

### ON THE HANDLING CAPACITY OF AN OPERATOR IN AIR TRAFFIC CONTROL

# Yu.M.Porkhovnik (Leningrad)

Available practical experience in air traffic control (ATC) permits the conclusion that the most convenient data-input system of electronic computers (EC), which in future will be widely used on ATC problems, is a device showing images on various types of cathode-ray tubes and auxiliary fluorescent screens. Of such indicator devices, cathode-ray tubes with visual display are most easily read for ATC systems. Such devices are described in the literature. The author discusses the features of the operator's work, representing him as a communications channel. The maximum handling capacity of an operator is taken as 40 bits.

The form and quantity of information that can be transferred from computers to an image in the case of an ATC system are determined. Information in letter-digit form is considered.

The concept of the blank as a letter-digital image on the indicator, giving brief information on the controlled object is discussed. Three types of blanks are considered as illustrative examples. The quantity of information in each type of blank is calculated, taking account of the probability of appearance of the individual significant parts.

The author defines the maximum number of controlled objects that an operator can handle, depending on the type and composition of the blank.

The influence of the operator's experience and the planned nature of air traffic on the allowable number of objects served is taken into account.

METHODS OF CORRELATION WORKUP OF NONSTATIONARY PROCESSES AND PRINCIPLES OF DESIGNING APPARATUS FOR OPERATIVE STATISTICAL ANALYSIS OF PHYSIOLOGICAL INFORMATION

G.A. Sergeyev and A.F. Romanenko (Leningrad)

The problem of operative statistical workup of physiological processes with the object of finding the quantitative parameters characterizing the dynamic properties of various physiological systems is acquiring great current interest.

The variability of the dynamic parameters of the physiological regulators connected, on the one hand, with the action of uncontrolled factors on the flow of the processes and, on the other hand, with the nonlinear character of the processing of information obtained from the external environment, is responsible for the nonstationary character of physiological information.

 $\frac{51}{}$ 

A peculiarity of the processing of information of this type is the unsuitability of the means of analog computer technology, which are based on the initial hypothesis that the processes to be handled are stationary.

The automation of the workup of processes, based on a nonstationary model of fluctuations is linked to the necessity of realizing very complex algorithms.

Correlation analysis of physiological processes and procurement of information parameters thus requires that the statistical correlation functions first be calculated in the time and frequency domains.

The correlation function in the time domain is

$$R_{(t,\tau)} = \frac{1}{T} \int_{t-\tau}^{t} \xi_{(t)}^{\circ} \cdot \xi_{t+\tau}^{\circ} d\tau,$$

where  $\xi_{(t)}^{0}$  is the centric random process.

The correlation function in the frequency domain reads

$$R_{(W,\nu)} = \frac{1}{W\Delta} \int_{W'-\Delta W'}^{W} G_{(W)}^{\circ} \cdot G_{(W+\nu)}^{\circ} d\nu,$$

where  $G_{(w)}^{O}$  is the normalized current spectral density of the random process.

We note that the calculation of variance in the frequency domain permits judging the functional state of the highest analyzer centers that realize the program of controlling some physiological parameter. From the viewpoint of /52 engineering realization of the algorithm of calculation of the statistical characteristics in the frequency domain, it is expedient to utilize the properties of the function f[T(t)] which reflect the character of variability of the current period of the random process, instead of the frequency.

To evaluate the current correlation interval of the physiological processes in the time and frequency domains, the author introduces a parameter of

the form  $\tau_{(t)} = 2 \int_{t-T}^{t} \theta_{(t)}(R_N(t,\tau)] d\tau; \quad \text{where } \theta(t) \text{ is a certain function al-}$ 

lowing for the variance of remote branches of the statistical correlation function obtained under the conditions of restricted selection.

A study of the properties of the weighting information function shows that an expression of the form  $\tau_{(t)} = 2\int\limits_{t-T}^t R_N^2\left(t,\tau\right)d\tau$ , where  $\theta(t,\tau) = R_N\left(t,\tau\right)$  may be used as an effective evaluation for the correlation interval of physiological processes.

The authors justify the possibility of designing an analog-type device to perform the task of calculating, on the real-time scale, the current estimate of the correlation interval of the physiological processes in the time and fre-

quency domains, recording them on suitable recorders.

Knowledge of the current estimates of the correlation intervals makes it possible to judge the changes in the handling capacity of physiological information elements, when signals of nonstationary type act on their input. To estimate the character of the nonlinear statistical transformations of information, the authors introduce the concept of transferred information function,

defined by a relation of the form  $\frac{N_{input}(t)}{N_{output}(t)}$ , where  $N_{input}(t) = \frac{\tau_{f}(t)}{\tau_{t}(t)}$  is

the ratio of the number of noncorrelated elements in the time domain to that in the frequency domain at the input of the physiological information system while  $N_{\text{output}}(t)$  is their ratio at the output of the system. The paper then considers the features of this function with respect to the case of an analysis of the self-adjustment of the human operator.

Possible practical applications of the proposed apparatus are discussed.

ANALYSIS OF THE ELECTROENCEPHALOGRAM DURING INTENSE MENTAL WORK, USING THE METHOD OF THE CORRELATION WORKUP OF NONSTATIONARY PROCESSES

L.P.Pavlova and G.A.Sergeyev (Leningrad)

Investigations of the mechanisms of the reliability of brainwork are of topical interest today.

A study of the electroencephalogram (EEG) during intense work previously led one of us (L.Pavlova) to the conclusion that the principle of functional substitution in the constellation of the nerve centers is one of the important mechanisms of the working capacity of the brain.

In a visual analysis of the EEG of 24 subjects (dextro-manual) we established the phenomenon of functional asymmetry in the pairwise functioning of the hemispheres of the brain, expressed in the prevalence of frequency oscillations of the biocurrents (13 - 80 cps) in the left hemisphere and the alpha rhythm (8 - 13 cps) in the right hemisphere. The latter result was also obtained by a number of other authors (Golikov, 1950; Khoruzhaya, 1962; Grinberg and Zubkov, 1963; and others) and confirms the existence of a dominant hemisphere in man.

On the other hand we discovered the phenomenon of a periodic shift of the "foci" of particular activity and, subsequently, of the alpha rhythm from one hemisphere to the other and back, in the course of the performance of intense mental or muscular work (Pavlova and Tochilov, 1960; Pavlova, 1962, 1963). These facts are in part confirmed by the data of Khoruzhaya (1962), Penov (1960) and Falaleyeva (1962). The findings permit speaking of functional displacements in the pairwise functioning of the hemispheres of the waking human brain.

The problem of elucidating the finer quantitative characteristics of the structural time parameters of the EEG demands development of special methods

/53

of operative spectral-correlation analysis (G.A.Sergeyev and A.F.Romanenko, 1963). The hypothesis of the locally-nonstationary character of the structure of the biocurrents was taken as basis. This hypothesis more effectively satisfies the requirements of adequacy of the quantitative results obtained than do the functional properties of the biocurrents, whose parameters may vary within rather short time intervals. The resultant method can be used as a system of graphic workup of EEG and also for calculating the current correlation intervals on digital computers.

The workup of the EEG shows that in the waking unfatigued state, in 4 dextro -manual subjects, the statistical indices of the correlation functions for leads from the left hemisphere, especially for the region of the motor /54 speech centers, differ from the corresponding values in the right hemisphere. An analysis of the current intervals of quantization of the parts of the EEG shows that the activity of the left hemisphere is greater than that of the right. In turn, the value of the interhemispheric asymmetry differs in the various portions of the brain and is likewise not constant, being at times higher for certain leads from the right hemisphere. We note that this is not always revealed by visual analysis of the EEG.

We also found an expansion of the frequency spectrum in the EEG during work, indicating the varying degree of desynchronization of the resonant neuron assemblies.

Individual calculations for a number of EEG leads reveal a more complex and dynamic picture of the functional shifts than those found by visual examination of the EEG. The paper gives a number of supplementary statistical characteristics of the EEG, calculated on the computer. Analysis of the course of electrical activity of the excited neuron assemblies may be performed by the dynamic pattern method.

The results not only confirm the existence of functional asymmetry in the pairwise function of the hemispheres of the waking human brain, but also indicate a complication of the function of the constellation of nerve centers during a period of strenuous work, owing to the mechanisms of interhemispheric and intrahemispheric functional shifts.

The method of mathematical processing employed permitted substantial supplementation and deepening of the EEG reading and, in particular, disclosed the phenomenon of low-frequency modulation of the instantaneous power spectrum of the alpha rhythm, whose character differs greatly from subject to subject. The resultant algorithms of operations analysis of the statistical EEG structure can be used as the basis for designing specialized equipment of the analog type.

#### THE USE OF COMPUTERS IN PROCESSING THE RESULTS OF PSYCHOLOGICAL EXPERIMENTS

Yu.M.Baraboshkin (Moscow)

It is a rather laborious process to work up the results of psychological

/55

tests, requiring great time expenditure by the programmer. In this respect, it is preferable to use electronic computers (EC) to process such results.

We developed a series of programs for universal computers, designed for the mathematical workup of empirical data. The programs permit an evaluation for sample averages and sample variances as well as an evaluation for correlation coefficients. It is also possible to compare two mean values calculated from the data of sampling observations of two general populations. The comparison is made by means of Student's criterion at a prescribed level of significance.

The program does not use external memory units for the computer. All the initial data and the program itself are handled directly in the operative memory of the computer. To increase the amount of data processed, the information is fed into the memory in "convolutional" form.

An arrangement is provided for operative control of the quantity of information on the computational results fed to the printer. The control elements of the program are set during the calculation. A complete calculation, using the program of estimating the means and the correlation coefficients, takes no more than 30-40 min.

STUDY OF THE INTERRELATION OF STEADY STATES OF THE PHYSIOLOGICAL FUNCTIONS BY MEANS OF A DIGITAL COMPUTER

K.P.Buteyko and D.V.Demin
 (Novosibirsk)

The steady state of the functional physiological system is defined by the n-fold realization of a k-dimensional random vector.

On introduction of a physiological load one must expect transition of the system to a new steady state, which is reflected in the deformation of the statistical structure of the vector; one-, two-, k-dimensional distributions, of a correlation matrix, and of indices of regression.

To analyze the interrelation of the human functions we used the correlation technique [V.S.Pugachev. Theory of Random Functions and its Application to Problems of Automatic Control (Teoriya sluchaynykh funktsiy i yeyeprimeneniye k zadacham avtomaticheskogo upravleniya). Fizmatgiz, 1962] which has given good results in econometric and sociological studies (G.J.Yule and M.J.Candell, Theory of Statistics. Gosstatizdat, 1960). The mathematical program made provision to obtain the following statistical indices: mathematical expectation, mean-square or standard deviation, asymmetry, excess of each vector component of the matrix of the normalized pairwise and partial correlation coefficitions, regression parameters, multiple correlation coefficients, and confidence intervals of the parameters.

To obtain the starting material we ran a mass clinical experiment (with about 100 subjects) during which the principal physiological functions were

synchronously recorded: pulmonary ventilation, oxygen and  $\rm CO_2$  content of the inspired and expired air and of the arterial blood, pulse, arterial oscillatory index, arterial blood pressure, and plethysmogram. The physiological load consisted in a change in the oxygen and carbon dioxide concentration in the inhaled air and painful hyper- and hypoventilation. The tests indicated a regular shift of the indices, which was interpreted as a change in the statistical structure of the vector.

The table of vector coordinates obtained as a result was processed on a digital computer. The calculation was used for checking the correspondence of the actual experimental material with a priori physiological concepts. An interpretation of the calculation results requires detailed anatomicophysiological analysis and may possibly supplement available quantitative data on the interrelation of the functional systems of the organism.

### STUDY OF THE DYNAMICS OF PHYSIOLOGICAL FUNCTIONS ON DIGITAL COMPUTERS

K.P.Buteyko and D.V.Demin
 (Novosibirsk)

In our last paper, the state of the functional physiological systems was characterized by a random vector whose statistical structure is deformed under the action of special tests. A continuous k-dimensional function k(t) was idealized as a series of steady states  $R_{\bf i}$ , whose alternation is induced by application of loads.

In this paper we shall analyze this continuous function. The program of mathematical processing provides for the calculation of the cross-correlation matrix  $\|\mathbf{r}_{p,q}\|$  of normalized coefficients [K.P.Buteyko and D.V.Demin, Cross-Correlation Analysis of Physiological Functions (Kross-korrelyatsionnyy analyz fiziologicheskikh funktsiy). Izv. SO AN SSSR, ser. biol., No.8, 1963].

The starting data was a synchronous multichannel record of the physiological indices calculated in the last paper. The record was tabulated at a time interval  $\Delta t = 10$  sec and was worked up for ten subjects on a digital computer; the maximum delay time was 600 sec.

In conjunction with a detailed physiological analysis, the cross- <u>/57</u> correlation method represents a means of verifying and deepening the quantitative concepts of the interrelation of the functional systems, by determining the following statistical parameters:

radius of autocorrelation; spectral density of the process; effective delay interval; reciprocal spectral density.

The classical linear cross-correlation analysis should be generalized to nonlinear interrelations by developing a method based, for example, on the principle of conditional probability or of entropy [cf. N.S.Rayman, On Variance Functions and Reciprocal Variance Functions (O dispersionnoy i vzaimnoy dis-

persionnoy funktsiyakh). VIIth All-Union Conference on the Theory of Probability and Mathematical Statistics, Tbilisi, 1963].

### CONTRIBUTION TO THE QUESTION OF AUTOMATION OF THE WORKUP OF ELECTROENCEPHALOGRAMS

# V.I.Kopanev and P.G.Shamrov (Moscow)

One of the major problems of modern medicine is to lighten human work in the system man - machine. The proper direction for solution of this problem lies in matching the abilities of the human operator with those of the machine. However, the capacity of human subjects undergoes constant changes depending on given conditions (external and internal). This proves the necessity of developing criteria that will permit a rapid evaluation of the functional state of an operator and of introducing the required corrections into the system man - machine. The EEG is often used as such an indicator. The visual method of interpreting an EEG is not applicable to these conditions, since it requires a large expenditure of time and work. Success is possible only by an automated workup of EEG on electronic digital computers (EDC). It is well known that, for an automatic analysis of EEG and for programming the work of the EDC, norms must be introduced into the computer memory (possibly, the limits of fluctuation) together with certain coefficients. Their presence will permit an automatic comparison with the experimental data and the introduction of necessary corrections into the system man - machine.

We studied the biological activity of the cerebral cortex during a functional test consisting of opening and closing the eyes, in order to find the <u>/58</u> quantitative patterns. The work was done on healthy subjects, using an SKTB electroencephalograph manufactured by the "Biofizpribor" and "Saney" Companies.

On analyzing this material we found that it was unnecessary to introduce the amplitude parameters of the EEG into the computer memory, since these parameters vary over an exceptionally wide range during the experiment.

This fact can be explained by their dependence on a large variety of conditions: design features of the electroencephalographs, pickups, methods of leading out the biocurrents, and physical state of the subjects.

Better-defined data were obtained on the frequency of the bioelectric rhythms. During a functional test, these rhythms were as a rule stable, in agreement with the results of other experimenters (V.A.Adamovich, 1956; P.I.Gulyayev, 1960, and others).

We found that a considerable amount of information can be obtained by comparing the bioelectric potentials of various regions of the cerebral cortex. In particular, we calculated the following:

- coefficient of interhemispheric asymmetry (CIA1) by finding the ratio of the integral values of certain frequencies from identical points of the right and left hemispheres;

- coefficient of intrahemispheric asymmetry (CIA2), by dividing the integral values of certain frequencies of the EEG from the frontal and occipital regions of the same hemisphere;

- coefficient of functioning (CF), by finding the ratios of the integral values of the biocurrents of the brain for each frequency while recording the

EEG with open and closed eyes.

We found that the value of each of these coefficients remains at a certain level during the study and that the coefficients are almost the same in most subjects examined.

All this permits us to recommend inclusion of such coefficients into the program of digital computer work.

The quantitative patterns obtained were the coefficients of functioning, the intrahemispheric, and the interhemispheric asymmetry. Of course, these will become still more precise with further advance in practical experience. Even today, it is obvious that such a quantitative approach to the evaluation of bioelectric phenomena will help considerably in improving a scientific analysis of the data, and will yield methods of finding the optimum relations in the system man - machine.

#### CONTRIBUTION TO THE PROBLEM OF AUTOMATIC DIAGNOSIS OF MENTAL FATIGUE FROM EEG DATA

/59

A.A.Genkin (Leningrad)

Changes that occur in the EEG on mental fatigue have been far from sufficiently investigated (Yu.Pratusevich, 1962; L.P.Pavlova, 1963; and others) and the data cannot be used for a reliable automatic diagnosis of the onset of mental fatigue. It is well known that even so distinct a change in the functional state of a subject as sleep does not always produce specific changes in the EEG if the features of the electrical process are evaluated on the basis of amplitude-frequency characteristics (Gess, 1961; L.P.Latash, 1963; and others).

In recent years, a parameter  $\Delta_T$  has been proposed for a quantitative characterization of EEG data. This parameter characterizes the mean asymmetry level of the durations of the rising and falling phases of the potentials during the time T (A.A.Genkin, 1962, 1963). Experimental studies have shown that during mental fatigue, as during deprivation of sleep, the mean level of asymmetry declines. However, if we consider successive levels of asymmetry, separated by a fixed averaging interval T,

$$\Delta_{\tau,1}, \Delta_{\tau,2}, \Delta_{\tau,3}, \ldots, \Delta_{\tau,n},$$

then the decrease in the mean level is not monotonic but of a wave form. As the interval T shortens, the amplitude of the oscillations  $\Delta_T$  increases. Since  $\Delta_T$  behaves in this way, it is impossible to decide from a single value, or even from several successive values of  $\Delta_T$ , whether there is in fact a state of fa-

tigue, and statistical discriminative procedures must be used to answer this question.

Assume that, for a given subject, the distributions  $F_1(\Delta_T)$  and  $F_2(\Delta_T)$  have been obtained in advance, the former for work in the waking state, the latter against the background of mental fatigue, determined from the direct indices of fitness for work.

The value of these distributions permits us to use a specialized computer to realize the following statistical procedure: For each value of  $\Delta_I$  we calcu-

late the ratio of the likelihood  $L = \frac{F_2(\Delta_T)}{F_1(\Delta_T)}$ . If L < 1, then mental fatigue

has not yet set in. Beginning with the first interval for which L > 1, we perform Wald's sequential sampling (1947) with the level of errors  $\alpha$  and  $\beta$  of the first and second kind, respectively, which are pre-assigned. If this leads to the decision that the state is one of waking, then the sequential sampling of

the probability ratio is broken off and the probability ratio  $\frac{F_2(\Delta_I)}{F_1(\Delta_I)}$  is again

tested for each value of  $\Delta_{\rm T}$ . If, however, in the sequential sampling the probability ratio exceeds the prescribed threshold, then with a given level of reliability  $\alpha$ ,  $\beta$ , one can diagnose the presence of mental fatigue.

The question of finding the optimum length of the time interval T, so as to ensure the most rapid detection of the subject's change of state, requires special study.

# EVALUATION OF THE FUNCTIONAL STATE OF AN OPERATOR IN AUTOMATIC DIAGNOSIS

R.S.Dadashev (Moscow)

The effectiveness of the work of an operator, and consequently of the entire system man - machine, depends largely on the functional state of the subject. A study of the closed system "man - machine" should therefore be based not only on the quantitative and qualitative characteristics of the control process itself but also on the electrophysiological indices of the operator.

The emotional-physical stress of the human subject can be judged on a combination (symptom complex) of physiological parameters, where various values of these parameters correspond to various states of the man. Not all the physiological parameters in the syndrome, however, have the same effect on the change of state of the organism. In the syndrome characterizing the general state we therefore distinguish, according to their significance, between basic (leading) and secondary physiological parameters. The leading physiological parameters for one state may be secondary in the evaluation of another state. In this connection, we introduce into the discussion the concept of "weight" (significance) of the physiological parameters in the symptom complex for evaluation of the state. The weight ratios of the physiological parameters constitute cri-

teria for an evaluation of the functional state and may be used as the basis for automatic diagnosis. The weight ratios of the physiological parameters in the symptom complex, however, undergo changes in the evaluation of different states.

#### APPLICATION OF THE POLY-EFFECTOR METHOD FOR EVALUATING THE PSYCHOPHYSIOLOGICAL ABILITIES OF AN OPERATOR IN THE SYSTEM MAN - MACHINE

<u>/61</u>

V.F.Onishchenko, A.A.Volkov and S.G.Mel'nik (Moscow)

The automation of control processes makes new demands on human subjects as the operator. While freeing man from heavy physical labor, the automatic machine does not eliminate his neuropsychic stress in accomplishing the control processes.

In these studies, we attempted to evaluate the working capacity of an operator during the control process not only from the indices of a poly-effector record of physiological functions (electroencephalograms, electromyograms, electrocardiograms, galvanic skin resistance, and pneumograms).

The experimental results showed that the same amount of work, with the same quantitative and qualitative characteristics, was performed by operators at the expenditure of different degrees of neuropsychic stress.

An increase in the emotional stress of the operator during control was characterized by an increase in the bioelectric activity of the high-frequency rhythms of the cerebral cortex, of the bioelectric activity of the muscles, the amplitude of the galvanic skin reaction, the rate of heart contractions, and the rate of respiration.

The use of the poly-effector method permitted a more complete evaluation of the individual psychophysiological capabilities of each operator during the control process and a comparative objective analysis of various control systems.

CONTRIBUTION TO THE QUESTION OF THE METHODS OF EVALUATING THE PSYCHOPHYSIOLOGICAL STATE OF A PILOT IN AN EMERGENCY SITUATION DURING FLIGHT

L.A.Kutayev-Smyk, I.P.Neumyvakin and V.A.Ponomarenko (Moscow)

An evaluation of the psychophysiological state of a pilot under actual flight conditions yields the optimum solution of the problem of including man in the control system "man - aircraft". In view of the progress in aviation technology and the increased demands on the pilot in flight, this question is becoming more and more important.

In flight, at the time of an artificially provoked emergency situation

(ES) in the preparation for landing, we measured respiration, pulse, pulmonary ventilation (by the aid of a portable bronchospirometer), ECG, change in thorax perimeter, verbal reaction time of the pilot, speed and altitude of flight, and other indices.

Two types of physiological reactions of the pilot to an ES were noted. The first type is characterized by a certain increase in all physiological indices during the period of expectation of the ES, and by a sharp rise in the pulse and the pulmonary ventilation on detection and elimination of the ES. The respiratory rate increased only slightly. Reactions of this type are characterized by rapid recovery of all physiological indices to their initial level within 1 min after elimination of the ES by the pilot.

The second type was characterized by a certain lowering of the level of physiological functions while awaiting the ES, a gradual increase in pulmonary ventilation and the respiratory rate, with the maxima reached only after elimination of the ES, while the pulse rate increased only slightly. Recovery of the physiological functions to their initial level took place within  $2-3\,\mathrm{min}$  after elimination of the ES.

As the pilots became accustomed to the occurrence of an ES, there was a tendency toward lessening of the change in physiological functions.

The pilot's delayed reaction time decreased during expectation of the ES and increased during its detection.

# APPLICATION OF SIMULATION METHODS TO THE STUDY OF THE ELEMENTS OF A BLOCK OPERATOR POINT

V.F.Venda (Moscow)

In connection with the work of the Central Research Institute for Combined Automation of a large thermoelectric central station, we solved the problem of establishing a complex system of centralized control run mainly by a control computer (CC) and an operator.

The controlled object consisted of a power unit: 2 boilers - 2 turbogenerators - 4 peak preheating boilers. The power of the unit was 200,000 kw, with production of a large quantity of heat. The complexity of the equipment to be controlled can be illustrated by the following example: For the system to operate under optimum regimes, it was necessary to control over 400 parameters and manipulate over 500 controls.

For the operator to be able to follow the operations of the control computer, all of them must be indicated on the data panel. This makes it mandatory to prove the adequacy of the information shown on the panel.

One of the methods of proof can be based on the theory of algorithms.

The determination of the amount of information from the purely technical

position in developing the data or instrument panel, the basic matching element of the system "man and automatic machine" is only the first and relatively simple stage. More complex questions arise in selecting the most effective method, with respect to the perception and processing of the information by the human subject, feeding of the information to the operator, and determination of the characteristics of the instrument panel and the control desk. It is of course generally known that there are as yet no methods for an analytic investigation of these questions. Experimental study requires the designing of special apparatus which must meet numerous requirements, most of them resulting from the necessity of having the perception and processing of information and the reactions of the subject correspond with the conditions of the actual object, in all their complexity.

Experience has shown that the results of laboratory studies of the partial relationships, let us say, between the brightness or density of the signals and the reaction time have limited application in solving the practical problems of the construction of multicomponent data panels.

Satisfaction of the above requirements is ensured by an experimental setup whose main part is an electronic model of the technological objects.

To simulate a block of a thermoelectric central power station, it is necessary to have an exact mathematical description of its dynamics and its statics, i.e., the transfer functions on all channels. The complexity of this problem is obvious when thinking of the fact that, to describe a power-plant block as an object of control with a sufficient degree of accuracy, it is necessary to set up a system of differential equations of the fortieth order.

It should be noted that preparation for the simulation, namely, the analytic description of the properties of the object and the calculation of its dynamics, is a big job. However, there is no need for a special experimental investigation of the principles of rational organization of the operative supervision and control, since data obtained in the development of the automatic control system and in finding the optimum design parameters can be used.

The use of an experimental setup, including a mathematical model of the "boiler - turbogenerator" block, permits us (under laboratory conditions) to find the optimum characteristics of the instrument panel and the control desk.

> METHODS OF RECORDING THE EXPERIMENTAL DATA USED IN STUDYING CERTAIN QUESTIONS OF ENGINEERING PSY-CHOLOGY

/64

V.I.Butov (Leningrad)

A correct experimental setup plays a leading role in research work. One of the most important aspects of experimental work is the recording of the experimental data, used as basis for analysis, for drawing practical conclusions, or for confirmation of theoretical propositions.

The success of any experimental work depends largely on the speed and accuracy with which the experimental setup permits the experimental data to be recorded as well as on the complexity of the decoding of the collected material.

The ever increasing requirements of quality, accuracy, and reliability of experimental data demand improved equipment which will permit more effective use of new and old techniques.

In setting up an experiment, however, it is not always possible to use experimental techniques that were previously worked out and tested in actual work. It is very often necessary to use entirely new methodological approaches to solve some specific problem.

In the work of any laboratory, a certain amount of practical experience is accumulated in the development of new and original methods, in the use of improved apparatus, and in the design and construction of new experimental setups. This experience may be highly useful for other laboratories working on closely related problems.

In this paper, the authors consider certain methods of recording experimental data used in their laboratory.

The methods of recording experimental data are discussed on the basis of examples of specific experimental setups, designed in the engineering psychology laboratory at the Zhdanov State University of Leningrad:

- 1. A setup for studying the work of railroad dispatchers.
- 2. A setup for studying the spatial and temporal components of the visual image.
- 3. A setup for determining the critical flicker frequency of a test object presented to the subject.
  - 4. A setup for determining the stability of clear vision.
- 5. A projection tachystoscope to record the latency periods of sensoriverbal and sensorimotor reactions.

After a brief introduction to each such setup, the recording of the <a href="https://experimental.org/">/65</a>
experimental data and the equipment used for this purpose are discussed in detail.

The author notes the possibility of measuring the frequency of periodically recurring processes by the Lissajous-figure methods. In particular, he discusses the measurement of the flicker frequency of the test object in determining the critical flicker frequency.

The use of optical and magnetic pickups in the recording system is discussed.

# CONTRIBUTION TO THE TECHNIQUE OF STUDYING VISUOMOTOR REACTIONS, TAKING ACCOUNT OF THE FEATURES OF PERTPHERAL VISION

# Yu.N.Verkhalo (Leningrad)

Today, in spite of the existence of various methods for studying the motor activity of human subjects, many investigators are devoting much attention to the study of visuomotor reaction time as an index of the degree of preparation for handling incipient loads (or after exposure to them).

Investigators have proposed many versions of techniques (and instruments) for investigating the visuomotor reaction time but, as a rule, these reduce down to the display of visual stimuli on small screens bounding the field of view. Such methods do not allow a study of reaction features connected with the inclusion of the peripheral zones of vision. Nevertheless, in studies on motor activity, special emphasis must be placed on the change in reaction time in view of the asymmetry of the nerve tracts and of the brain hemispheres.

A study of the reactions of a subject to signals arriving in the peripheral zones of vision permits a more rapid and more distinct determination of the functional state (and of the shifts) of the nervous systems and the motor apparatus.

For such studies the author, in collaboration with Professor A.B.Gandel's-man, has developed a chronospheroelectroreflexometer device for studying the latent visuomotor reaction time to light stimuli at any point of the retina, with exact localization of these points, exact recording of the strength of the optical stimulus, and the possibility of associating it with other stimuli. By the aid of this instrument, which consists of a hemispherical screen, a projection stand (we used a modernized stand from a type PRP industrial perimeter) /66 with a set of stimuli and a control desk, the reactions can be studied under laboratory conditions, separately for the right and left eyes, taking account of the features of peripheral vision. The inclusion of an additional chronometric unit permits determination not only of the latency period but also of the total reaction time.

However, since this apparatus is rather complicated, a new panoramic device was developed and is now being used. This consists of a projection head with a lens and photographic frames (in the form of light stimuli or athletic situations), a control desk and elements for the subject's response. The stimuli are projected on a folding or shifting panoramic screen. Two electrical chronometers in the control desk measure the latency and motor period of the motor reactions and other reactions. The contact elements for recording the subject's response can be mounted in the instruments, controls etc., thus increasing the similarity of the test conditions to those of real activity.

#### REFLEX MEASUREMENT AND ITS DEVELOPMENT IN THE NEAR FUTURE

# A.B.Gandel'sman and Yu.N.Verkhalo (Leningrad)

The measurement of the reaction time and the magnitude of response reactions in their development in the "reflex arc" is the subject of reflexometry.

Reflexometry measures all exteroceptive (distant and contact), interoceptive and proprioceptive reflexes such as, for instance, the visuomotor, audiomotor, tactual-motor, interoceptive-motor, etc. reflexes.

Hardly anyone today disputes the necessity of accurate measurement of the latency period, the stimulus value, and the duration of the response reaction in studying reflexes, both unconditioned or inborn reflexes and conditioned reflexes acquired during the lifetime of humans or animals. Reflexometry, however, has not yet been properly developed on the level of modern technology.

The failure adequately to appreciate reflexometry makes it very difficult to solve problems of labor and of specialized expert testimony, labor devices, medical supervision of physical training and fitness for such training, and research on physiology, psychology, and hygiene on the level of modern technology.

If the need for the development of reflexometry is recognized, our man- <u>/67</u> ufacturers of medical supplies should pay specific attention to the manufacture of reflexometers.

Primarily, it is desirable to manufacture reflexometers of optimum design for visuomotor and audiomotor measurements (perhaps, compound meters).

The first step would be to select the practically most useful prototypes of instruments and - an important point - of various attachments, to be placed into production. These can be of two types, stationary (laboratory) and portable (dismountable), readily adaptable to complex conditions of investigations in industrial shops, athletic fields, etc.

The manufacture of stationary (laboratory) devices should take priority, since they would serve as the original instruments and as standards for the portable devices. The stationary instruments should be suitable for detailed investigations with a wide accuracy range for measuring both stimuli and responses as well as for measuring time.

It is important for such instruments to provide 1) facilities for exact dosage of the stimulus, for instance, light in luxes, shape and size of the luminous spot, sound in frequency, loudness in decibels, etc.; 2) provision for strict localization of the stimulus. Special attention should be paid to the peripheral regions of the retina, the distance from stimulus to receptor, the extent of the response reaction with an accuracy to within 0.001 - 0.0001 sec, its qualitative characterization, etc.

As far as possible, every possible effort should be made continuously to trace the processes taking place in the "reflex arc", especially at the nerve centers (for instance, the action potentials). Continuous and accurate quantitative recording of the reflex processes determines the success of stationary reflexometers.

Portable reflexometers should be adapted to the complex conditions of their use (they must not break down, even when exposed to considerable vibration, and their readings must not be influenced by temperature, humidity, barometric pressure, etc.). Their accuracy and the number of processes that can be measured depends on the specific practical problems. For example, a study of the latency period of a simple motor reaction to sound, to sudden factory noise, and to other stimuli, does not require an accuracy higher than 0.01 - 0.05 sec, according to practical requirements. For a study of the latency and motor periods of the visuomotor reaction, extensive use should be made of projection reflexometers which permit convenient stimulation of many industrial conditions.

There is every reason today to promote extensive use of reflexometry in all its forms.

DEVICE FOR EXPERIMENTAL STUDY OF THE SPEED OF INFORMATION PROCESSING BY AN OPERATOR UNDER ACTUAL CONDITIONS

<u>/68</u>

# A.I.Galaktionov (Moscow)

The speed of processing information by an operator under real conditions is investigated (real control system or its model; real events, actually existing in the object and consisting of a combination of several parameters which have exceeded the allowable limits and signify some trouble in the controlled object; real duration of the working shift; real continuous streams of such events; knowledge by the operator of the flow sheet, the diagram of the controlled object, the possible events and the law of probability distribution of their occurrence or of the probabilities of their signs).

The device consists of a simplified model of a mnemonic diagram of a cement plant, of generative random numbers, a unit of temporary operating regime, a unit for assigning probabilities, a measuring unit, a unit for determining the correctness of the operator's work, a unit for switching events, a unit for controlling the operation of the elements of the plant, and an automatic recording unit. There is an additional device for studying the action diagram of the human operator in solving these problems.

# 100 111 **1 200** 1 1000 1 2011

RECEPTION OF INFORMATION BY HUMAN SUBJECTS: EVALUATION OF INFORMATION RECEIVED, SENSORY PROCESSES AND CHARACTERISTICS OF THE SENSORY SYSTEMS, SIMULATION OF PERCEPTION AND RECOGNITION, CODING OF INFORMATION

CONTRIBUTION TO THE PROBLEM OF THE QUANTITATIVE EVALUATION OF EVENTS OF COMPLEX STRUCTURE

# A.I.Galaktionov (Moscow)

An operator's solution of real problems of automatic control often reduces to a determination of the causes (or "subcauses") of trouble in the controlled object or in the technological process (determination of events).

Such problems are highly complex, since each event is itself a combination of several successive stages of the complex selection of parameters.

The complexity of the determination of the quantity of information contained in such events, by the aid of formulas of the information theory, leads to a painstaking analysis of the structure of such events and the scheme of their interrelations.

The author introduces the concepts of the group of interrelated events and of the structural scheme of events, which form the basis for a classification of these events according to degree of structural complexity; they permit a considerable simplification of the calculation of the quantity of information according to formulas of the information theory.

HOW TO EVALUATE THE QUANTITY OF INFORMATION IN SYMBOLS, WHEN THE LENGTH OF THEIR ALPHABET AND THE PROBABILITY OF THEIR OCCURRENCE ARE UNKNOWN

# P.B.Nevel'skiy (Kharkov)

In experiments within a study of the memory capacity, the same word list for memorizing was divided into various numbers of logical groups. The labels given to the groups were conventional concepts whose extent decreased with increasing number of groups. It was assumed that, with increasing number of groups into which the list was divided and with decreasing extent of each group, the amount of information per word entering into the group of narrowest extent would decrease, since the indeterminacy of this word within the limits of the group would decrease. In another case, a list of pairwise associated generic and species concepts was presented and the generic concepts were reproduced in terms of species or the species in terms of generic. It was postulated that the generic concept contains less information than the species concept, since the choice of the generic concepts, the extent of which includes the given special concept, is more restricted than the choice of the species concepts contained in the extent of the generic concept. In these cases, how-

ever, it was impossible to calculate the quantity of information, without knowing the number of characters in the symbols and the probability of their occurrence.

An empirical method was developed for evaluating the quantity of information in words and concepts. The following postulates were made in this connection: The probability of occurrence of any symbol equals the probability of predicting or guessing the occurrence of that symbol. The probability of guessing the occurrence of a symbol can be evaluated by the frequency of guessing, representing the ratio of the number of correct guesses to the total number of guesses. The quantity of information per symbol, in bits, may be evaluated as the negative binary logarithm of the frequency of guessing or as the binary logarithm of the ratio of the total number of guesses to the number of correct guesses.

To check the effectiveness of this method, the author made experiments in guessing two-digit numbers. The alphabet of two-digit numbers equals 90. They appear with equal probability 0, 0 (1) and carry 6.49 bits of information. The object of the experiments was to establish the extent to which an empirical evaluation of the quantity of information would differ from its true value. Twelve mathematical students participated in the experiments. They were instructed to guess or, more correctly speaking, simply to write out, on the experimenter's order, the first two-digit number coming into their mind. About 2500 numbers in all were written out. The frequencies of occurrence of the various numbers were calculated. These frequencies range from 0.003 to 0.032. The mean frequency was 0.011. One thousand lists of ten two-digit numbers each were then prepared from a table of random numbers and the mean frequency of guessing the numbers from each of the 1000 lists was calculated. It was from this mean frequency of guessing that the quantity of information was calculated. From 1000 empirical values obtained for the quantity of information contained in the two-digit numbers, 993 differed less than 0.5 bit from its true value and 762 less than 0.25 bit.

To evaluate the quantity of information in a list of words presented by us, when this list was divided into various numbers of groups, we asked the subjects to guess and to write out the first words belonging to any group that came into their mind; for example, 16 words from organic nature, 8 plants,  $\frac{71}{h}$  trees, or 2 evergreen trees. The number of words they were asked to think of corresponded to the number of words of this group in our list whose quantity of information we wished to evaluate. The quantity of information per word was evaluated from the frequency of guessing this word, and the mean quantity of information per word in the list from the mean frequency of guessing per word. The experiments showed that, when our list of 32 words was divided into 2, 4, 8, and 16 groups, the mean quantity of information per word was evaluated respectively at 8.1, 6.3, h.h, and 3.1 bits. This evaluation was based on the following number of guesses for each value obtained, respectively: 39,936; 29,696; 9984; 2176.

The mean quantity of information contained in the generic and species concepts, composing 50 associative pairs, was similarly evaluated. The quantity of information which on the average is carried by a species concept in this list, if the generic concept was known, was evaluated at 3 bits, and the mean

quantity of information in a generic concept, if the species concept was known, at 0.6 bit.

In principle this method is not original. The guessing method was first used by Shannon (1951) to evaluate the conditional entropy of the characters of an English printed text. He assumed that the conditional entropy  $H_h$  determines the difficulty of guessing the  $h^{th}$  character from the h- l preceding characters. The difficulty of guessing was evaluated from the mean number of attempts required to find the correct answer.

#### SUBJECTIVE REDUNDANCY OF INFORMATION PERCEIVED BY MAN

# B.B.Kossov and R.A.Ratanova (Moscow)

It is useful to distinguish objective and subjective redundancy of information perceived by the human subject. In this connection we introduce the following definitions:

Distinctive criterion of objects (DC) - a criterion by which objects are distinguished from each other.

 $I_{\mbox{min}}$  - the quantity of information contained in the minimum sufficient number of distinctive criteria.

 $I_{max}$  - the quantity of information contained in the actual number of distinctive criteria.  $I_{max}$  is calculated from the probability of occurrence of the corresponding maximum number of conditioned connections between the criteria and the reactions. The objective redundancy of information  $R_{ob}$  is

defined by the formula  $R_{ob}$  = 1 -  $\frac{H}{H_{max}}$ , i.e., unity minus the relative en-

tropy, where H is calculated with allowance for the minimum number of distinctive criteria and  $H_{\text{max}}$ , with allowance for their actual number. In the

case where H = 
$$I_{min}$$
,  $H_{max} = I_{max}$ , we have  $R_{ob} = 1 - \frac{I_{min}}{I_{max}}$ .

A dominant attribute or trait (DT) determines the quality of action (or reaction) of a person. A recessive trait (RT) is opposite to a dominant trait. Resultant traits (ReT) equally determine the quality of action of a human subject after perception of objects. Perceived information ( $I_{sub}$ ) is contained in a dominant trait ( $I_{d.t.}$ ) or in resultant traits ( $I_{re}$ ). The subjective redundancy of information ( $R_{sub}$ ) is calculated by the above formula for  $R_{ob}$ , but in this case  $H_{max}$  is found taking account of the number of conditioned connections of the dominating or resultant traits, while H is found by starting out from the minimum number of all distinctive traits.

In our experimental study we investigated the dependence of the magnitude of R<sub>sub</sub> on the variation of each of two factors: a) the degree of difference between two versions of the distinctive traits in two objects; b) the degree of indeterminacy of the problem put to the subject in the verbal instructions.

Redundant information not only increases the reliability of the subject's action (Glezer, Nevskaya, Seredinskiy, Tsukkerman, 1962) and sometimes decreases his reaction time (L.B.Filonov, 1961), but with a certain change in the conditions can become necessary for successful activity of a person, i.e., it can become useful. This was one of the considerations that led us to study the factors determining the value of R<sub>sub</sub> and in part determine the technique of the study.

In our experiments the subjects were shown two objects,  $A_1\,B_1$  and  $A_2\,B_2$ , differing in two attributes A and B (slope and length of the lines). The objects were shown on a screen with equal probabilities ( $P_1 = P_2 = 0.5$ ). The second of the distinctive attributes was the only source of redundant information. In all series of experiments  $R_{ob}$  was constant ( $I_{min} = 1$  bit;  $I_{max} = 2$  bits;  $R_{ob} = 0.5$ ).

To determine  $R_{\rm sub}$ , the subjects were shown the objects  $A_1\,B_2$  and  $A_2\,B_1$  with a new combination of variants of the same attributes. From the character of the reactions to these control objects, we found the dominance of one of the attributes or the equal activity of the two attributes (Kossov, 1954). We then determined  $R_{\rm sub}$  for each subject or for the group as a whole.

Other conditions being equal, the value of  $R_{sub}$  in our experiments varied in the different subjects in the range 0  $\leq$   $R_{sub} \leq$  0.5. If one attribute was completely dominant (reactions to all the controlled objects in accordance /73

only with the variants of this attribute),  $R_{sub} = 1 - \frac{1}{1} = 0$ . When the attributes were equivalent,  $R_{sub} = 1 - \frac{1}{2} = 0.5$ .

The value of  $R_{\rm sub}$  depends on the degree of difference between the variants of the distinctive attribute in the objects being discriminated. This dependence was most pronounced under the conditions of "indeterminate" preliminary instruction. Here, the subjects received no information on the distinctive attributes of their objects. The reactions were developed on the principle of "each-time reinforcement" (modified method of A.G.Ivanov-Smolenskiy; Kossov, 1956). At a definite degree of difference between the objects in the two attributes, we obtained a mean value of  $R_{\rm sub}$  almost equal to zero. When we increased the degree of difference in one of the attributes, we increased its dominance, leading to an increase in  $R_{\rm sub}$ . The dominance may perhaps be based on the mechanism of negative induction. We can therefore conclude that negative induction performs the function of decorrelation of attributes in objects, thereby decreasing the redundancy of the information perceived. Our results are thus in agreement with the suggestion of V.D.Glezer and I.I.Tsukkerman (1961) that neural induction encourages the "decorrelation of images".

The arrival of information about stimuli by way of the semantic system may to a certain degree change the level of redundancy of information that is characteristic for the same situation, but under conditions of indeterminate instructions. Thus, if the instructions give specific variants of one distinctive attribute and the required reactions ("concrete positive instructions with request to react to one definite attribute"), then in most cases this leads to dominance of the prescribed attribute and decreases  $R_{\rm Sub}$ . In the presence of

a relatively small difference between the variants of the prescribed attribute, however (but still 2-3 times as great as the threshold of discrimination!), and of a great difference in the other attribute, conditioned connections to this other attribute frequently occur. Consequently, the regularity of perception of the visual objects may counteract the influence of the information contained in the instruction. In some cases, for example, in the case of general, insufficiently concrete instructions, we even observe a paradoxal influence of the instructions on  $R_{\rm sub}$ : the informational content of the instructions should increase  $R_{\rm sub}$ , but in reality the opposite was observed with statistical reliability, namely, a decrease in  $R_{\rm sub}$ . All these examples suggest that estimation of the information arriving by way of the semantic system is indeed a complex process.

# THE PROCESSING OF AMBIGUOUS VERBAL INFORMATION BY THE HUMAN SUBJECT

G.V.Yeyger (Kharkov)

One of the important problems in studying the decoding of speech by human subjects is the problem of semantic noise, i.e., of noise arising not in the communications channel itself, but produced by the absence of clear rules of transition from the system dispatching the communication to the system of the perceiver.

Such noise may, in particular, result from the ambiguous use in the communication, of linguistic elements and their combinations.

Psychologically, the occurrence of ambiguity is explained by the different attitude of the participants in verbal communication to the linguistic means: the transmitter of information concentrates on the choice of linguistic means with one definite meaning to express a given content, whereas the receiver of the information decodes the communication only on the basis of the verbal material received, which may lead to an interpretation other than that intended by the author.

The following experiment was performed on Russian and German texts, in order to define the pathways of decoding verbal information: the subject was shown a text including one or several propositions admitting of ambiguous interpretation, and was requested to read the text. The actual attitude to what was read and the delay in the reading process were determined by means of a special device. After reading the text, the subject was questioned in detail.

The experiments showed that:

- 1. In cases where the factual information differed only insubstantially from that stated (from the point of view of understanding the entire communication) neither re-reading nor any delay in understanding were observed.
  - 2. If correct understanding was possible only with a wider knowledge of

the material previously given, or if it required a detailed acquaintance with the subject matter of the exposition, we observed a certain slowing in the process of reading; non-specialists in the field made mistakes in selecting the correct version.

3. Whenever the proposition was in direct contradiction with the information obtained after reading the entire necessary context, the proposition was re-read. Since proper selection is homologous with the correction of noise, the process of eliminating semantic noise obeys Shannon's Tenth Theorem: to eliminate errors, at least the same number of bits of information must flow through the correcting channel.

/75

Such a correction can be accomplished by keeping the transformations invariant (without changing the amount of information or increasing it).

For cases where the ambiguity is removed by using the formal indices of the narrow context, it is possible to set up a program for automatic editing of the text, facilitating diagnosis and correction of certain semantic noise.

The completeness of such a program will depend on the degree of formalization of the context.

In organizing the transmission of informational and command information, the necessity of eliminating semantic noise must be taken into account.

### DEPENDENCE OF THE SPEED AND ACCURACY OF INFORMATION PROCESSING ON THE DISCRIMINABILITY OF SIGNALS

# M.A.Dmitriyeva (Leningrad)

In designing control desks and in determining the degree of activity of an operator in remote control, it is insufficient to be guided merely by the psychophysiological thresholds of the sensory organs. It is also necessary to know the "operative thresholds", i.e., the levels of discriminability at which there is no substantial influence on the speed and accuracy of the operator's processing of the information received by him.

We investigated, in this direction, visual discriminability and considered first only a single form: discrimination of the height of two parallel lines. This study was conducted by means of two experimental methods.

In the first method, the subjects sorted cards  $(55 \times 90 \text{ mm})$  on which two short parallel lines, 2 mm in thickness and 20 and 20 mm in height or 20 and 20 +  $\ell$  mm in height were entered. The difference  $\ell$  was kept constant in each series, from  $\pm$  0.5 mm in the first series to  $\pm$  10 mm in the eleventh series, i.e., from one to twelve times the psychophysiological threshold. In each series the subjects received 30 cards, 10 of which had equal lines and 20, unequal lines. The subject's task was to reject the cards with lines of unequal height, as "poor drawings". The time spent was measured with a stopwatch. Thirty-three subjects were used in all.

In the second method, two signals were projected onto a screen, in op-  $\frac{76}{20}$  posite contrast. Two lines appeared before the subject on a small screen, 50 × × 50 mm, on the test desk. The subject was instructed to depress a white button if he considered the lines equal and a red button if he considered them unequal. The lines were 15 and 15 mm or 15 and 15 +  $\ell$  mm in height. In the first series  $\ell$  = 0.5 mm, in the last, 15<sup>th</sup> series,  $\ell$  = 7.5 mm. Each series consisted of 30 frames, 20 of which had a pair of lines of unequal height and 10 a pair of equal height. The rate was arbitrary, and the reaction time was recorded on the strip chart of an ink-recording oscillograph. Fifteen subjects were used.

The quantity of information per signal (pair of lines) was calculated from the probability of occurrence of a signal and remained constant at 27.54 bits for all of the series. Each equal pair of lines erroneously considered unequal by the subject, meant a loss of information equal to one bit. The rate of information processing depended on the number of errors and on the time taken to evaluate all 30 frames (or cards) of the series. In the second group of experiments, besides the total time, we also estimated the latency periods of reaction to a frame with lines of equal height.

The results of the two methods were the same. The quantity of information transferred (bit/sec) increases with increasing difference of height of the lines being compared, but after this difference reaches 10 psychophysiological thresholds, a further increase of difference has no effect on the speed and accuracy of information processing. The quantity of information transferred per second remained constant for a difference from 10 to 20 times the psychophysiological threshold in the first group of experiments and from 10 to 30 times the threshold in the second group of experiments. (The threshold of discrimination of the height of the transilluminated signals was only half that in the first group of experiments.) The latent reaction periods likewise obey this law: They decrease with increasing difference, but above ten times the threshold value they fluctuate slightly about a line parallel to the abscissa axis.

The quantity equal to ten times the pyschophysiological threshold was called the "operative threshold" of visual discrimination of the height of two parallel lines. Beyond this threshold, in the interval studied by us, a change in the difference has no effect on the speed and accuracy of information processing.

#### A METHOD OF MEASURING PERCEIVED DATA

/77

# S.M.Kozlovskiy and Yu.I.Ionin (Moscow)

In solving various problems of motion-picture and television technology it is important to establish the laws of variation in the physical parameters of images with any variation in the conditions of observation. For example, in the problem of reproduction of sound, we must establish the laws of variation of the reproduced degree of contrast; in developing a method of estimating the geometric distortion in motion pictures, we must estimate the variation of the perceived amount of these distortions as it depends on the various conditions of perception.

The current method of solving these problems is to evaluate the perception in units of the differential threshold of sensation. However, as shown by experiment, this method of measurement cannot be used in many cases, owing to the fact that above-threshold quantities are not additive to quantities of the differential threshold of sensation.

The method of measuring the subjective values by comparing them with a system of objective equivalents may be used to solve a number of problems. These equivalents are test objects with physical parameters that vary in accordance with a certain law.

The use of this method in estimating perception in studies of sound reproduction and geometric distortions in motion pictures has shown a number of advantages; the quantities perceived are expressed in objective units, it is possible to make wider use of the mathematical apparatus in staging the experiments, there is a low dispersion of the responses of observers, etc.

EFFECTIVENESS OF THE PERCEPTION OF SYMBOLS IN SUPERVISION AND CONTROL, QUANTITATIVE EXPRESSION AND CONNECTION WITH THE ACCURACY OF PERCEPTION

V.Ya.Dymerskiy (Moscow)

The evaluation of the possibility of human supervision and control of numerous types of apparatus and machines, the selection of certain optimum design features, the determination of the optimum methods of perception as necessary conditions of supervision and control, and the development of the corresponding techniques for training all depend substantially on the quantita— /78 tive estimate of the effectiveness of perception and its connection with the accuracy of perception.

The perception of many symbols of objects and phenomena of the real world, including the perception necessary in the supervision and control of apparatus and machines, is accomplished on the basis of an association of these symbols with the sensations from other symbols. In the general case, the adequacy of such perception depends on the representation of the functional relation between the quantitative characteristics of the perceived and sensed symbols and certain other quantities that appear as conditions of perception. Let

$$A = F(B, C, D, \ldots, N) \tag{1}$$

be the above functional dependence, A the quantitative expression of the sensed symbol, B the quantitative expression of the perceived symbol, C, D, ... N the quantities characterizing the conditions of perception,  $P_A$  the threshold of discrimination of the symbol A (differential threshold of sensation).

Since the quantity A depends not only on B but also on C, D, ... N, it follows that the change (or difference) of A is determined by the change (or

differences) of the values of all the independent variables B, C, D, ... N. It is by the changes (differences) of all these quantities that the sensed change (difference) of A is in fact determined.

The relation between the complete change (difference) of A on the change (differences) of B, C, D, ... N, may be expressed by the total derivative of the function (1):

$$\frac{dA}{dB} = (A)_B + (A)_C \cdot \frac{dC}{dB} + (A)_D \frac{dD}{dB} + (A)_N \frac{dN}{dB}$$
 (2)

The corresponding sensed change (difference) of A is expressed by the following quantity\*:

$$\frac{\begin{bmatrix} \frac{dA}{aB} \\ A \end{bmatrix}}{A} : P_{\mathbf{A}} \tag{3}$$

Each of the quantities

$$\frac{(A)_B}{A}: P_A; \left[\frac{(A)_C}{A} \cdot \frac{dC}{dB}\right]: P_A; \left[\frac{(A)_D}{A} \cdot \frac{dD}{dB}\right]: P_A, \dots, \left[\frac{(A)_N}{A} \cdot \frac{dN}{dB}\right]: P_A.$$

determines the share of the represented change (difference) of A, caused respectively by the change (difference) of each of the quantities B, C, D, ... N.

The ratio 
$$\left[\frac{(A)_B}{A}\right]$$
:  $P_A$ , on the one hand, and

$$\left[\frac{(A)_C}{A}\frac{dC}{dB} + \frac{(A)_D}{A} \cdot \frac{dD}{dB} + \dots + \frac{(A)_N}{A} \cdot \frac{dN}{dB}\right] : P_A$$

on the other, characterize the extent to which the dependence of A on B is "masked" by the dependence of A on C, D, ... N and, consequently, how "effective" the perception of the quantity B is on the basis of its association with the quantity A.

Let us call the expression

$$\frac{\left[ (A)_B \right] - \left[ (A)_C \frac{dC}{dB} + (A)_D \cdot \frac{dD}{dB} + \dots + (A)_N \frac{dN}{dB} \right]}{\left[ (A)_B \right]} \tag{4}$$

the coefficient of effectiveness of the perception of B by means of A  $(K_{ep})$ .

<sup>\*</sup> Cf. V.Ya.Dymerskiy 'Method of Quantitative Analysis of the Perception of Spatial and Spatial-Temporal Relations". Collection "Inzhenernaya Psikhologiya" (Engineering Psychology), Moscow State University, 1964.

1. If

$$(A)_{C} \frac{dC}{dB} + (A)_{D} \frac{dD}{dB} + \dots + (A)_{N} \frac{dN}{dB} = 0$$

and, consequently  $K_{ep}$  = 1, then the change (difference) of A is completely due to the change (difference) of B. Other changes do not "mask" this dependence so that there exists an optimum possibility of perceiving the change (difference) of B by means of the change (difference) of A.

In this case we shall consider the effectiveness of perception  $(E_p)$  of B by means of A as also being numerically equal to unity.

2. If

$$[(A)_B] > \left[ (A)_C \cdot \frac{dC}{dB} + (A)_D \cdot \frac{dD}{dB} + \dots + (A)_N \frac{dN}{dB} \right] > 0$$

and, consequently,  $K_{e,p}$  is smaller than unity but greater than zero, then the changes (differences) C, D, ... N will "mask" the dependence of A on B and decrease the effectiveness of perception of B by means of A the more, the smaller the value of  $K_{e,p}$  in this interval (0; 1). We shall consider the effectiveness of perception as being numerically equal to  $K_{e,p}$ . Consequently,

$$0 < E_{P} < 1$$
.

3. If

$$|(A)_B| = \left| (A)_C \cdot \frac{dC}{dB} + (A)_D \cdot \frac{dD}{dB} + \dots + (A)_N \cdot \frac{dN}{dB} \right|$$

and  $K_{ep} = 0$ , this means that the changes (differences) of A due primarily to the changes (differences) of all the other elements (C, D, ... N) might be said to cancel each other\*.

It is logical that, in this case, the perception of B by means of A will be impossible so that  $E_p = 0$ .

4. If

$$|(A)_B| < \left| (A)_C \cdot \frac{dC}{dB} + (A)_D \cdot \frac{dD}{dB} + \ldots + (A)_N \cdot \frac{dN}{dB} \right|,$$

then  $K_{e\,p}<0$ . This means that the change (difference) of A as a result of the changes (differences) of B is completely "masked" by the changes (differences) of the quantities C, D, ... N, and might be said to be "lost" in them. In this case, of course, the perception of B by means of A is likewise impossible. The effectiveness of  $E_p$  in this case, for simplicity and by analogy with the pre-

<sup>\*</sup> See preceding footnote.

ceding case, will likewise be put as zero.

5. Starting out from the above, the accuracy of perception of B by means of A  $(T_p)$  may, in the general case, be characterized by the following quantity:

$$T_{\mathbf{r}} = T_{\mathbf{r}\,max} \cdot \mathbf{E}_{\mathbf{r}},\tag{5}$$

where

$$T_{P max} = \frac{(A)_B \cdot B}{100A \cdot P_A}$$

TIME CHARACTERISTICS OF THE PROCESS OF DETECTION AND IDENTIFICATION OF AN OBJECT IN THE FIELD OF VISION

Yu.B.Gippenreyter and L.P.Shchedrovitskiy (Moscow)

The time deficit or time limit characterizing the work of an operator in modern technological systems is responsible for the acute interest in studies of its time parameters. In this connection the study of the motor processes in the human receptor systems becomes particularly important, and especially in the visual analysor since the movements of the eye are a necessary component of any visual activity.

The orienting and focusing movements of the eyes, which fix the region of clear vision on the object, are a reliable indicator of the detection reaction. At the same time, the instant of termination of the fixing movement is the beginning of the process of identification and of central processing of the signal which concludes the execution of motor reaction.

The problems of this study were: 1. To investigate the latency periods of the fixing movements of the eyes (detection times) as they depend on the site of appearance of a signal in the field of vision. 2. Their comparison with the latency periods of simple motor reactions under the same conditions. 3. The measurement of the time of the complex motor reaction on random occurrence of a signal in various regions of the field of vision.

In accordance with these problems we developed a technique assuring the random production of a signal at any of the points  $10^{\circ}$ ,  $20^{\circ}$ ,  $30^{\circ}$ , and  $40^{\circ}$  from the point of fixation by four straight and four oblique directions, recording the components of the complex reaction  $(T_{\rm cr})$ :  $T_1$  - latency period of the training jump of the eyes;  $T_2$  - duration of the jump;  $T_3$  - time of recognition of the signal and central switching of the command to the effector;  $T_4$  - duration of the effector movement. In a special series, under the same conditions, the simple reaction time  $(T_{\rm sr})$  was measured. The latency periods of the jump of the eyes was measured by means of an electro-millisecond-meter (EMS), started at the instant the signal was given and stopped by the potential fed from the eye across an amplifier to the input of the EMS.

The results of the experiments showed a substantial similarity between the latency period of the orienting-focusing reaction of the eye and the simple motor reaction of the hand in both absolute value and character of the dependence on the angular deviation from the center of fixation.

The mean values of the latency periods of the jumps of the eyes (and of the simple motor reactions) vary from 230 msec (for 10°) to 290 msec (for 40°) in all directions and are independent of the direction.

The mean duration of the fixing jump depends on the angular distance of the signal from the center of fixation. In our experiments it was 60 msec for  $10^{\circ}$ , 70 msec for  $20^{\circ}$ , 90 msec for  $30^{\circ}$ , and 100 - 120 msec for  $40^{\circ}$ .

The time of the central element of a complex reaction depends on the individual traits of the subjects. Two groups of subjects are distinguished according to this parameter: the "fast" (central processing time 120-200 msec) and the "slow" (central processing time 410 msec).

In these experiments we observed cases of recognition of signals that occurred before or without fixing movement of the eyes, mainly when the signals were 10° from the center of fixation. This fact confirms the existence of an operative field of vision larger than the region of central vision, in which the visual information is processed.

#### EYE MOVEMENTS IN VISUAL SELECTION AND SEARCH

/82

# V.E.Mil'man (Moscow)

We studied the features of eye movements in performing tasks of visual selection. The task was to find a pathway in a "maze" by making several choices in succession according to a prescribed rule.

When the performance was mastered, the mean selection time decreased from 2.14, sec to 1.07 sec and the mean number of eye fixings per selection decreased from 3.16 to 2.25. The most probable value in the series of duration distribution of fixation was 0.2 sec. When the performance had not been mastered, the maximum duration of a fixation exceeded 4 sec, and after learning the longest fixation was 2.2 sec.

When the complexity of the task was increased, the mean selection time increased from 0.74 sec to 1.51 sec, i.e., to almost double, and the number of fixations of the eye per choice increased from 2.22 to 3.31, i.e., by almost half. The most probable duration of a fixation in a simple choice was 0.2 sec, and the maximum 1.0 sec, while in the complex choice the most probable duration increased to 0.3 sec and the maximum to 1.4 sec.

These results permit the conclusion that the time characteristics of eye fixation can be used as an index of the subjective complexity of the visual tasks being performed.

# STUDY OF THE OPERATOR'S WORK IN SEARCHING FOR INFORMATION WHEN PERFORMING A TASK OF SEQUENTIAL ARRANGEMENT FOR SERVICE

Yu.B.Gippenreyter and G.N.Il'ina\*
(Moscow)

In analyzing the work of an operator, two forms of search for information are clearly differentiated: information search followed by immediate servicing and information search with delayed servicing (see the abstract of the paper by V.P.Zinchenko and N.I.Mayzel'). The object of the present work was to study /83 the information search with delayed service.

With a large number of objects requiring service the operator must, at a given instant, select a limited number of objects and arrange them in sequence for service according to certain criteria.

In our experiments, we used various background objects and critical objects. The criterion for the critical condition was the number of the object.

We found that in performing the task of sequential arrangement, collectives of fifteen or more critical objects are difficult and super-difficult. Work with them is characterized by constant occurrence of errors and an increase of total time to several tens of minutes. A comparison of the task of sequential arrangement with immediate service to follow, when a large number of critical objects are involved, shows that in the latter case the quality of the operator's work declines. Sequential arrangement for service, which imposes a heavy load on the memory, has the positive aspect of good orientation in the situation.

# EXPERIMENTAL STUDY OF FACTORS INFLUENCING PERCEPTION BY PERIPHERAL VISION

N.D.Zavalova, V.A.Ponomarenko, V.M.Sivolap, and L.A.Kitayev-Smyk (Moscow)

When an operator is overloaded with visual information, he often overlooks important visual signals. In this connection, the operative field of vision and, in particular, the perception of various objects by peripheral vision has been studied in separate projects (Yu.B.Gippenreyter, A.F.Pakhomov and A.M.Izmail'tsev).

We studied the features of perception of a moving indicator by peripheral vision. We investigated the effect of indicator speed and location on the time and accuracy of signal perception, when various objects were simultaneously

<sup>\*</sup> L.P.Shchedrovitskiy, M.D.Gustyakov, M.A.Karena and V.N.Safonov participated in this work.

perceived by central vision.

We tested three indicator positions and four indicator speeds in combination with three different tasks for the operator: 1. To fix the gaze on a point being sighted. 2. To follow a moving pointer in the field of central vision.

3. Together with the last task, to solve simple mathematical problems. The /84 results of the operator's work on a simulated control desk were recorded on an oscillograph.

The studies disclosed the conditions ensuring timely and correct perception of information by peripheral vision when the operator's attention was considerably burdened by objects perceived by central vision.

#### VARIATION IN DISCRIMINATIVE VISUAL SENSITIVITY UNDER EXTREME CONDITIONS

V.V.Suvorova (Moscow)

This work was done under laboratory conditions, using the equalization method to measure the discriminative visual sensitivity. The setup permitted precise selection of the standard light stimulus and detection of the errors made by the subjects in an attempt to obtain the same light as the standard on the screen.

Five to six experiments were made on each of ten subjects. Three of them were devoted to measurements of the discriminative sensitivity under ordinary quiet conditions (background), and two or three measurements of the discriminative sensitivity under extreme conditions (stress experiment). The extreme conditions were established by giving the subjects an unsolvable problem on the sampling counting of the number of stimuli used in the experiment and applying a strong auditory stimulus of a pure tone, by means of which the subjects were informed of the committed errors.

A comparison of three indices - mean error of discrimination, coefficient of variation, and number of reactions without error - showed that the differential visual sensitivity in the background experiments differed in different subjects: Eight subjects out of ten matched better with weak stimuli whereas two subjects equalized better with a relatively strong stimulus.

Complicating the work conditions (stress experiments) resulted in considerable changes in the discriminative visual sensitivity of all subjects. The subjects were divided into two groups according to the character of their change in sensitivity. The first group included the four subjects whose discriminative sensitivity declined under extreme conditions at all luminous intensities applied; the second group included the six subjects whose sensitivity increased or (in one case) remained unchanged.

An analysis of the character of the activity, behavior, and errors of the subjects whose discriminative sensitivity increased under extreme conditions showed that the increase in discriminative sensitivity is a function of the /8

typological traits of the subjects, intensity and concentration of the excitation process or intensity and concentration of the active discriminatory inhibition. In other words, productivity of discrimination is ensured whenever, in addition to the excitatory inhibitory process also the active inhibitory process plays a leading role.

A decrease in the discriminative visual sensitivity under extreme conditions took place in subjects with relatively weak productive cortical processes on transition of the cortex to ultraliminal defensive inhibition.

DETERMINATION OF THE SENSORY THRESHOLD OF THE HUMAN AUDITORY
ANALYSOR BY THE METHOD OF THE CONDITIONED—CONDITIONED—
UNCONDITIONED REFLEX

G.F.Plekhanov, G.A.Aksenov, A.P.Voyarkina, V.V.Vedyushkina, L.P.Nagayev and Ye.I.Osinskaya (Novosibirsk)

Two principal methods of developing conditioned reflexes are known, the conditioned-unconditioned where an indifferent stimulus is associated with another stimulus causing an unconditioned reaction (the Pavlovian techniques and their modifications) and the conditioned-conditioned, including the second signal system in the reflex arc (the Ivanov-Smolenskiy technique). In the present work we used a combination of these methods. The subjects, instructed in advance, were to perform some elementary operation on perception of a certain signal (depress a key). If this operation is not performed, a painful electrocutaneous reinforcement is given. If the subject depresses the key in the absence of a signal, he also closes the circuit for the electrocutaneous reinforcement.

The application of this technique to determination of the auditory thresholds permitted introduction of the concept of subjective and objective threshold, and likewise that of the lowering of the subjective sensory threshold as a result of the elaboration of a conditioned-conditioned-unconditioned reflex. The subjective threshold here means the minimum intensity of the signal consciously perceived by a given subject under given specific conditions. The objective threshold of sensation is that intensity of the signal which is not yet sensed by the subject but already causes certain shifts in some physiological functions.

We measured the subjective thresholds in several subjects, with and without electrocutaneous reinforcement (over 200 tests) and developed a method /86 of statistical analysis of the results. It was shown that, in the development of the conditioned-conditioned-unconditioned reflex, the subjective threshold is lowered in all subjects (in some cases to half or less). It can be assumed that the application of electrocutaneous reinforcement to the training of operators will improve their sensitivity to certain signals.

### AUDITION OF VERBAL SIGNALS TRANSMITTED AGAINST THE BACKGROUND OF WHITE NOISE

# I.M.Lushchikhina (Leningrad)

Verbal signals, when transmitted over a great distance, undergo considerable changes or are lost entirely under the influence of various kinds of noise: internal noise, depending on the organization of the verbal material and on the dictor, on the one hand, and the auditor on the other; external noise, depending on the quality of the communications link and external influences.

In this connection the reliability of an operator receiving various types of information in oral verbal form may be inadequate, possibly leading to unnecessary complications or even accidents.

The general problems of this study were: first, to elucidate the limits of the auditor's ability for correct interpretation of a communication distorted by noise or being of inadequate completeness; second, to find the optimum conditions of organization of the verbal material and proper selection of the auditors.

To solve these problems we devised an experimental setup by means of which verbal signals could be mixed with white noise and the intensity levels of both signal and noise could be varied.

During the experiments we varied the composition of the programs, the intensity of the input speech and of the masking noise, and the grouping of the auditors (according to age, general level of education, occupation, and dominant language).

The invariant factors were the rate of transmission of the spoken signals, the dictor, the ratio of intensity of speech to noise, the experimental conditions, and the state of the auditor's hearing (only subjects with normal hearing were used).

The programs in the first stage of the study included words of various types (of varying length, position of the accented syllable, and qualities of the accented vowel and of the surrounding sounds) and various word combinations (the determining criteria were the quality of the controlling word and the type of its syntactic connection with the controlled word).

The results showed that a different degree of mastery of Russian 487 under all conditions affects the recognition of the spoken signals. Auditors of dominant Russian-language background were far more often able to recognize the verbal signals than auditors of nondominant Russian tongue (difference up to 15%). The character of the substitutions also differed under these conditions. Subjects of predominantly Russian tongue made fewer substitutions, but all of them made attempts to understand words or word-combinations. Subjects of nondominant Russian tongue made far more substitutions, but these were primarily not semantic but phonetic. As a result, meaningless sound groups ap-

peared.

The experiments confirm the assumption that the speech-to-noise ratio plays a decisive role in the recognition of spoken signals. For the lower components, the audition still gains by comparison with the higher components. Apparently, the high level of noise (and of speech) leads to a more rapid onset of fatigue.

Analysis of the audition of various elements of the program was performed on three aspects: lexico-semantic, morphologo-syntactic and phonetic.

Special attention was given to phonetic analysis. The experiments confirmed the conclusion that the lengthening of a word increases the auxiliary criteria for recognition and thereby enhances the accuracy of audition. Substitutions of the transmitted signal by closely related sounds were most often observed in the case of short words. Thus, monosyllabic words were correctly heard under unfavorable conditions in 12.5% of the cases, while six-syllable words were correctly interpreted in 40.6% of the cases. Here, 30% and 14.6% of the words were, respectively, substituted.

We also observed a tendency toward more accurate audition of words beginning with a vowel, in comparison with words beginning with a consonant (the difference being about 10%).

The position of the accented syllable in the word also plays a certain role. If the accent came at the end of the word, then the entire word was recognized considerably more easily (the difference in recognition of words with accent on the first and third syllables is 20%).

The preservation of the rhythmic structure of the word, with a more or less distinct recognition of the elements of the accented unit (the accented vowel and parts of the consonants surrounding it) is obviously an important factor in perception. These elements were studied in detail.

The experiments confirmed the assumption that the loudest of a series of vowel sounds of varying loudness (a, o) mask the consonants surrounding them, thereby diminishing the reliability of correct recognition of the words containing them. The phonetically weak vowels (y, i) in this case give more favorable conditions for correct audition.

The consonants surrounding the accented vowels were analyzed in the same way (all the consonants were divided into five groups, according to the /88 degree of their phonetic power: sonants, spirants, sibilants, plosives, and fricatives). The position of the consonant to the right or left of the accented vowel was taken into account in the analysis. We found that for the left position the most favorable is a spirant and for the right position, a sibilant. The poorest are left sonants and right plosives.

The experiments showed that the morphological laws play no substantial role in the correct recognition of individual words. We found that neither the part of speech nor the distinct, or more or less merged, etymological root have any effect on the auditor's decision in selecting a response.

We have scheduled studies on the dependence of the accuracy of recognition on the probability of occurrence of verbal signals.

We also intend to study the influence of syntactic connections on the recognition of phrases.

#### ON THE CYBERNETIC MODEL OF CONSTANT PERCEPTION

# A.M.Parachev (Leningrad)

The problem of constancy of the visual image of a perceived object is discussed in terms of cybernetics. The authors successively consider the following models of constant perception:

- 1. Computational model. On the basis of measurement of the parameters describing the situation, the parameters of the image of the objects formed on the retina are converted in the visual center to their true value.
- 2. Correlation model. The objects possess a system of statistically interconnected symbols, some of them being invariants of a transformation group. In the visual center, on the basis of the invariant criteria, a statistical conclusion is formed as to the true value of the other parameters of the object.
- 3. The Gestalt model. Two objects are placed in the field of vision; one known object with attributes unambiguously connected with it and one object unknown whose attributes are to be determined. On the basis of the distortions produced on the retina of the image of the first object, the situation parameters are calculated for this object first and then the parameters for the second object.
- 4. Adjustment model. The image of an object on the retina is the re- 189 sult of application of an operator belonging to a certain group. The parameters of this operator (the attributes of the situation) are unknown but, in compensation, the probability distribution for these parameters is known. This distribution simulates the "adjustment" of the subject. A certain value of the operator parameters is selected and applied to the image on the retina. If this distribution changes, then the transformation applied to the image also changes, which means that the form-qualities of the object change.

In the real perception process a constancy mechanism functions according to any one of these models, depending on the concrete conditions of perception.

### DEVICE FOR AUTOMATIC RECOGNITION OF PATTERNS AS A MODEL OF HUMAN PERCEPTION

#### V.A.Makhonin (Moscow)

If, in automatic recognition of forms, a human-type classification of

description is required, i.e., of signals from a system of transmitters-receptors, then the recognizing device must possess the properties of perception, and in designing the automatic machine one must start out from these properties.

The author shows the possibility of establishing a scheme of a recognizer with the properties of integrity and constancy.

The solutions of such a device are preserved under transformations of the signals accompanied by losses of information (integrity) and under isomorphic transformations of the object of recognition (constancy).

### SIMULATION OF CONSTANT PROPERTIES IN THE RECOGNITION OF PLANE FIGURES

# V.A.Makhonin and V.P.Savel yev (Moscow)

The plane images of many objects do not change their values for classification by a human subject if they undergo changes that can be described by a continuous group of transformations. Such a constancy in an automatic machine may be provided by a device for reduction of an image to the standard form.

Two methods of reduction are technically convenient:
 integral, based on the properties of two-dimensional moments
 of different orders;
 differential, making use of singular points of the images.

<u> /90</u>

# CONTRIBUTION TO THE QUESTION OF THE OPTIMUM CODING OF INFORMATION TRANSMITTED TO THE OPERATOR OF A CONTROL SYSTEM

B.F.Lomov (Leningrad)

In remote-control systems, the operator cannot directly observe the controlled objects; the information transmitted to him through the system of technical devices is usually coded. To obtain a high effectiveness of the operation of the control system, a method of coding the information must be selected such as to ensure the assigned speed and reliability of its reception by the operator.

Optimum coding of information presupposes the solution of problems such as the choice of the physical alphabet of the signal, the "saturation" of each signal with information to the extent allowed by the information transmission rate, and a number of other problems.

A solution of all these problems is impossible without an analysis of the mechanisms by which the operator receives and processes the information.

The operation of reception of information includes the processes of search (and detection), discrimination, identification, and recognition. Their interrelation is determined by the specific problems of the operator's work.

The development of a method of coding information to be transmitted to the operator simultaneously encompasses the development of a certain organization of the above processes. Obviously, the optimum method of coding will be one developed in accordance with the characteristics of these processes and of their interrelations.

In the choice of the physical alphabet of signals, the basic criterion is the degree of their discriminability which is limited by the values of the differential sensitivity ("resolving power") of the human analysors.

It could be assumed that the high differential sensitivity of the analysors with respect to the individual properties of the stimulus would permit formulation of an alphabet of sufficient length from one-dimensional stimuli (assuming that the length of the alphabet is limited only by the level of the discrimination threshold of the individual property). However, experimental results indicate that, in using such an alphabet, the rate of information /91 reception is very low and, at the same time, the unreliability and ambiguity of reception is high. The optimum conditions for discrimination occur only where the difference between a pair of adjacent one-dimensional stimuli considerably exceeds the threshold value. This fact limits the allowable length of the signal alphabet. Another limitation is the low ability of a human subject accurately to identify one-dimensional stimuli.

The length of the alphabet, meaning also the "saturation" of each information symbol, can be increased if multi-dimensional stimuli are used. Here, too, however, there are limitations. The perception of multi-dimensional stimuli of complex groups of stimuli is not just the simple sum of parallel discrimination processes. It has been established experimentally that there is a certain sequence of discrimination of the various properties (attributes) of a given stimulus, that under certain conditions one of them may mask others, and that the same subjective effects may be obtained for different relations between certain attributes. There is reason to assume that an increase in the number of attributes of a signal will permit an increase in the rate of information reception only up to a certain limit. All these factors limit the speed, accuracy, and reliability of the processes of search, discrimination, and identification of multi-dimensional stimuli.

The processes of detection, discrimination, and identification are not the only elements in the overall operation of information reception. Its final step is recognition, i.e., decoding of the signal. The speed, accuracy, and reliability of decoding depend on the structure of the process of recognition which is, in the final analysis, determined by the relation between the set of signals to the set of objects (or to the set of their states).

According to experimental data, the method of coding that is optimum with respect to the process of recognition is the method in which the number of informative attributes of the signal equals the number of attributes of the object. Here, optimum results are attained in cases where the attributes of the

signal reproduce, even if partially, the attributes of the object, thus ensuring the active participation of the association-by-similarity mechanism in the acts of recognition.

# CONTRIBUTION TO THE QUESTION OF THE RELIABILITY OF THE PROCESS OF RECOGNITION

# B.F.Lomov, R.M.Mansurov and G.V.Sukhodol\*skiy (Leningrad)

Psychologically considered, recognition is a system of sensory and intellectual actions which comprise the acts of detection and discrimination of the signal, its identification, and its association with the object represented. The reliability of recognition can be evaluated from the indices of its accuracy and speed.

The reliability of recognition is a function of many variables, the most important of which are:

- a) degree of discriminability of the signal, taken in relation to the resolving power of the human receptor system;
- b) number of attributes of the signal, related to the human ability for simultaneous processing of information arriving over several channels:
- c) length and complexity of the characters, with reference to the peculiarities of human memory.

The discriminability of each individual attribute of the signal may be expressed by the value of its divergence from the differential threshold of the corresponding analysor:

$$Q = \frac{n}{\Delta}$$

where Q = discriminability of the attribute;

n = divergence of the attribute as its objective characteristic;

 $\Delta$  = threshold value of the divergence, determined by the differential threshold of the analysor.

The probability of error-free recognition is a function of the discriminability  $R_{ef} = f(Q)$ .

For each of the inputs of the recognition system we may find a value of Q such that  $R_{e\,f}$  asymptotically approaches unity.

The alphabet with which the operator must work may consist of either one-dimensional or multidimensional symbols. The identification of multidimensional symbols can be accomplished by either successive or simultaneous scanning of their attributes.

In the latter case, several channels for the reception of information op-

erate in parallel. However, human ability to make simultaneous use of several sensory channels is limited.

Under actual conditions of work, a man usually does not scan all attributes in sequence but may, depending on the specific conditions of recognition, more or less "jump" from one to the other, thus considerably shortening the recognition time. Here the identifying attributes of maximum discriminability from all others are picked out of the conglomerate.

The recognition time is a function of the number of "steps" that must be taken to relate the signal to the object. The number of such "steps" depends on the organization of the memory processes.

A detailed study of the components of the recognition process and of its structure is an extremely important condition for solving the problem of optimum coding of the information fed to the operator, and of enhancing the reliability of its reception.

# THE ROLE OF CLASSIFICATION IN THE RECOGNITION OF OBJECTS FROM THEIR EXTERNAL OUTLINE

/93

# V.A.Ganzen and R.M.Granovskaya (Leningrad)

In the act of cognition, information about a visual form (outline) enters the central nervous system from the retina and oculomotor apparatus, is compared, and then processed. A number of authors (V.D.Glezer, A.L.Byzov, L.M. Vekker, B.F.Lomov and V.P.Zinchenko) who investigated the structure and function of the visual system have come to the conclusion that several primary attributes can be differentiated in the object of visual perception. The incoming information is evidently processed in several stages.

In the model under consideration, two stages of this processing are described. In the first stage, the outline is distinguished first, after which the circumference and its curvature at each point are determined; the outline is then broken up into a finite number of intervals, and each such interval is described by a group of primary attributes. The following are used as such attributes: 1) the condition for zero curvature; 2) the sign of the curvature; 3) the maximum absolute value of the curvature; 4) the value of the absolute increment of the slope of the tangent; 5) the local dimensions of the interval. Each attribute is characterized by a number, and each interval of the outline is characterized by a group of such numbers. The code of the outline as a whole consists of an ordered sequence of such groups. The code obtained is compared with the code retained in the memory, and in this way recognition can take place.

Codes of this type are invariant under transformations such as the transformations of similarity, rotation, parallel translation, linear deformations of tension and shear, and special forms of nonlinear transformations.

In the second stage the resultant codes are transformed. The following

transformations, more specifically, are considered:

- 1) Transverse filtration: Those groups of the code possessing an assigned value of one attribute are distinguished. This operation may serve for recovery of the most informative parts of the contour.
- 2) Longitudinal filtration: Out of all groups of the code, one and the same attribute is distinguished. This operation may be used to recover the most informative primary attributes.
- 3) Recovery of the attribute or group of attributes with the same value in all code groups: These attributes are attributes of the object as a whole and can be isolated into a separate group standing ahead of the code.

As a result of such transformations we obtain a new code, consisting of the attributes of the contour as a whole (secondary). The description becomes shorter and changes into an unordered sequence of secondary attributes.

A classification of objects is constructed based on the secondary attributes, distinguishing the attributes of the sets and subsets and the attributes of the individual object. These attributes have various weights. The strategy of recognition becomes rigidly connected with the task, i.e., it is required either to recognize the set, or the subset from which the object is selected, or to recognize the object from its individual attributes.

Classification permits economies in notation, storage, and counting of information, in agreement with experimental data obtained by psychologists especially by P.I.Zinchenko who has shown that mastery of the classification process by a child sharply increases the number of objects remembered.

# DEPENDENCE OF THE RATE AND ACCURACY OF PERCEPTION AND RECOGNITION OF VISUAL DISPLAYS ON THE CHANGES IN THEIR ANGULAR DIMENSIONS

# M.K.Tutushkina (Leningrad)

One of the most important problems of engineering psychology is the problem of selecting the optimum conditions for the presentation of information to an operator. This problem becomes particularly important in studying the conditions of presentation of displays on the screen of a cathode-ray tube, since the rate and accuracy of recognition of visual displays largely depends on such characteristics as the contrast between display and background, brightness of the display, and its angular dimensions. All these characteristics are closely interrelated and exert a great mutual influence. However, for more detailed investigations it is necessary to differentiate each characteristic and assume, for purposes of the study, that the others are optimum.

In this investigation, the problem was to study the influence of a change in angular dimensions of a given display on the accuracy and rate of its perception and recognition by the operator.

Analysis of literature data on the investigation of the spatial threshold of vision and a determination of the optimum angular dimensions of various displays showed that this particular problem had previously been studied with the test object shown to the subject at a certain distance from him, in reflected light. Only in a very few investigations, all of a preliminary nature, was the operator shown luminous displays on a screen.

In the project under discussion, a luminous display was shown to the <a href="#pg-95">/95</a>
subject on a screen not more than 75 cm from him. This distance was held constant throughout the experiment, and the angular radii were varied by changing the linear dimension of the display on the screen.

Four series of experiments were staged. Two of them were devoted to a study of the rate and accuracy of perception of unknown displays of various angular radii with limited or unlimited presentation time, and the other two series concerned the recognition of displays of various angular radii under the same conditions.

As a result of the experiments we determined the thresholds of separate vision and recognition of the contours of simple and complex plane figures. visual displays, and separate parts and letters in the display with limited and unlimited presentation time. We found that, for unlimited presentation time. the contours of simple figures in the form of a triangle, trapezium or polygon are perceived at an angular radius of 6° and are recognized without error at an angular radius of 12°, whereas the same contours, but complicated by various external or internal details such as letters, are perceived at an angular radius of 18° and recognized at an angular radius of 15°. Details in the display are distinctly perceived at a minimum angular dimension or spacing of 3º (linear dimension, 1 mm), which is three times as great as the threshold of normal visual acuity in reflected light, and almost agrees with the results of D.N. Lazarev on the resolving power of the eye for two luminous points, which is 2 140". The threshold of recognition of the smallest detail was somewhat lower, about 2. For unlimited presentation time, there is no substantial difference in the value of the spatial thresholds between the perception of an unknown display and its recognition. There is, however, a considerable difference in the time of error-free reading, which, for recognition, is only half that for perception of the display. Perception and recognition of a complex display with all its detail is completely free from error at an angular radius of 33 - 35.

When the presentation time was limited, we noted a considerable difference between perception and recognition both in speed (evaluated by the threshold presentation time) and in accuracy (evaluated by the spatial threshold). We found a certain dependence between the presentation time of a display and its angular radius under the conditions of error-free perception and recognition. The threshold of vision of the smallest detail in an unknown display at presentation times of 0.05 sec is 30°, i.e., ten times as great as for unlimited presentation time. For recognition, this threshold is 6 - 8°.

The results of the study make it possible to determine certain opera- /96 tive spatial thresholds of perception and recognition of visual displays, their contours, and smallest details, at limited and unlimited presentation time.

### VISUAL PERCEPTION OF A DISPLAY WITH LIMITED PRESENTATION TIME

 $I(I) = I(\langle I \rangle - \langle I \rangle - \langle I \rangle)$ 

1 11

# M.K.Tutushkina (Leningrad)

The operator's work in control systems is extremely varied. In a psychological analysis of this activity, the cognitive processes, by which the opertor receives and processes information, occupy the primary position. These processes include sensation, perception, representation, and thought. In reading displays from a screen, the operator must first of all perceive the display with all its details and characteristics, then correlate the given display with the mental image of the display already formed in his imagination, i.e., solve the problem of cognition and decoding of information.

The object of our study was to evaluate the configuration of displays relative to their structure as geometrical figures, and the correlation of the structure of a display with the information encoded in it. Apparently, this problem can be solved only by comparing the processes of perception and recognition of displays. Under real operating conditions, the operator must identify visual displays. But the process of recognition itself is the result of a certain training, and the complete structure of visual perception is condensed in it. It follows that, to investigate the perception of displays of a certain configuration and to evaluate them, one must select a method whereby this process can be unrolled and its structure defined. In other words, we must study the process of formation, i.e., the gradual formation of a complete idea of the display. For a more detailed study of the structure of the perception of a complex display, it was necessary to limit the time of perception and study the perception of the display with limited presentation time.

A projection tachystoscope with a time relay was the experimental apparatus used in this study. Time delays of 0.03, 0.05, 0.07, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35 sec were used in the experiments. The subjects were shown unknown displays (of angular radius  $1^{\circ}40^{\circ}$ ) and were instructed first to perceive them and then to sketch them. The displays were exhibited until completely perceived by the subjects.

The displays were divided into three complexity groups. The complexity of a display was determined by the number of details and characters, and by /97 the size of the details and their position in the display.

The experiments permitted us to follow the gradual formation of the visual concept of the display as it depended on the presentation time and complexity of the display. Simple displays were completely perceived in 0.03 sec, displays of moderate complexity in 0.07 sec, and complex displays in 0.3 sec.

An analysis of the experimental data permitted us to distinguish a certain structure in the process of formation of a concept of the display under time deficit conditions.

First, the subjects distinguish the contour of the display as its most

informative part together with the internal or external details that are easiest to distinguish (line with a circle, hatched portions); then the internal and external details are distinguished that are smaller but far apart. The smallest details and the closely spaced details (two lines, short lines) are refined after complete perception of the major details.

The greatest difficulty in perception was produced by letters inside or outside the contour of the display.

The character of the formative process is expressed by scrutiny and discrimination of each of the smallest details of the display.

The structure of the process is reflected in the order in which the elements of the display are sketched by the subjects.

Under time deficit conditions, the spatial thresholds of vision vary considerably. Exposure for 0.03 sec is sufficient to see a detail with an angular radius of  $30 - 40^{\circ}$ , but almost ten times as long is needed to see a detail of an angular radius of 3 to  $6^{\circ}$ .

This experimental work permitted an evaluation of the configuration of displays or of geometric figures with respect to their discriminability under conditions of time deficit.

### SELECTION OF THE CONTRAST FACTOR IN THE PERCEPTION OF A VISUAL DISPLAY

## V.Ye.Bushurova (Leningrad)

The perception of a visual display is greatly affected by conditions of its presentation, such as its angular dimensions, flicker frequency, and contrast between display illumination and background illumination.

The object of this study was to find the optimum contrast factor between display and background illumination. The experiments were conducted in darkness, to which the subjects had been adapted in a 15-min period. On a /98 screen 70 mm in diameter appeared a display in the form of a geometric figure representing some real object. The image was projected by a projector behind the screen, i.e., it was transilluminated.

The screen was 70 cm from the subject's eyes. The angular radius of the display on the long side of its outline was about 33.

In the experiments we used reverse contrast, i.e., the display was illuminated on a dark background. The choice of reverse contrast was based on the data by A.A.Stepanov who showed that when a display is thrown on a screen by transillumination, reverse contrast has several advantages over direct contrast. In our study it was important to determine the contrast factor for perception of the display under these conditions.

The experiments to find the optimum contrast were divided into four series.

In Series I, the displays were shown to the subject at five contrast factors, 32%, 44%, 64%, 86%, and 97%\*. The subjects were already familiar with the displays. They were asked to identify the display and estimate the contrast by giving one of five grades. The latency period of sensoriverbal reaction and estimation of the contrast showed that a contrast with the factors 32% and 44% was extremely inconvenient, since it involved visual stress. The highest grade (5) was given by the subjects to a 97% contrast, and the lowest to a 32% contrast. The contrast of 86% was estimated at grade 4, 64% at grades 3 or 4, and 44% at grade 2 or 3.

In Series II, the purpose was to find the optimum contrast factor. The only difference from Series I was that the subject was shown the display for a limited period of 0.05 sec.

Because of the more difficult perception conditions in this series, we used the errors of identification as an index, which permitted a more accurate definition of the optimum contrast level.

The results of Series II suggest that there are no substantial differences in the accuracy of identification of the displays in the range from 60 to 97% contrast. The subject's estimate of contrast agreed with the data on identification accuracy.

In Series III, the displays were shown to subjects unfamiliar with them, i.e., what took place was not a process of recognition but a process of perception. As was shown in one of our earlier studies, perception - as a formative process - is much more suitable than recognition for discovering the difficulties produced by various conditions of display on the indicator (angular dimensions, brightness, etc.). This applies equally to the contrast. It was precisely for this reason that this series of experiments was based on the perception of displays.

This series, in which the contrasts with factors of 65%, 75%, 85%, and 95% were analyzed, likewise showed no perceptible difference between the contrast data.

In Series IV, we used the principle of having the subject himself give the degree of contrast most convenient for perception of the display. The subject was allowed to establish the desired contrast on the screen: 65%, 70%, 75%, 80%, 90%, or 95%.

Three levels of display brightness were used: 20, 30, and 50 nit.

The experiments with 50 subjects showed that, at a display brightness of 30 and 50 nit, 85% was the optimum contrast factor and at a brightness of 20 nit, it was 90%.

<sup>\*</sup> The displays were photographed on film and the contrast factor was then measured.

The conclusion may be drawn from all the series that the working range for perception of a display should be the range from 65 to 95% contrast. A contrast of 85 - 90% is optimum in this range.

# CONTRIBUTION TO THE QUESTION OF THE CRITICAL FLICKER FUSION FREQUENCY IN STUDYING THE PERCEPTION OF A VISUAL DISPLAY

# T.P.Zinchenko (Leningrad)

One of the specific problems in engineering psychology is to investigate the perception of visual displays on the screen of a cathode-ray tube. One of the factors influencing visual perception is the flicker frequency of images on a screen. The visual sensation experienced on reaching the critical flicker frequency (CFF) of a discontinuous light stimulus is equivalent to the visual sensation of a stimulus constant throughout the time of emission.

The technical conditions under which a display is shown in modern systems make it necessary to determine the minimum CFF since, with increasing amount of information supplied in unit time, the noise resistance of the system decreases. To avoid flickering in modern television, a rate of 50-60 frames a second /100 is ordinarily used, and in motion pictures, 48 frames a second.

In many studies on psychology, physiology, and lighting technology, the effect of various factors on the CFF has been investigated, especially the brightness of the light stimulus (direct relationship). An increase in the angular dimensions of the flashing image has the same effect on the CFF as an increase in brightness.

The relation of the CFF to the brightness of the flashing source has been studied for picture images (television, motion pictures) and for luminous spots. Inadequate study has been devoted to the variation in CFF in the perception of complex plane figures, displays of a certain configuration, of small angular radius. It is well known that every variation in the area of the illuminated surface of an image entrains a variation in the area of the illuminated surface of the retina, which in turn affects the CFF of an intermittent light stimulus.

The object of the present study was to investigate the dependence of the CFF on the brightness and configuration of a transilluminated display.

The experimental technique was as follows: After 10 minutes of dark-adaptation the subject, by changing the rotational speed of a two-blade disk obturator (with a light-dark ratio of 1:1) defines the position at which the flickering of the image disappears. The frequency was recorded by the Lissa-jous-figure method\*.

<sup>\*</sup> The experimental setup was designed by engineers V.I.Butov and D.N.Chartorizhskiy.

The data presented consisted of displays which were geometric figures of various configurations. Their angular radius was 33. When the configuration of the display was changed, the area of the illuminated surface also changed (for example, at a source brightness of 120 nit, the illumination of the displays varied from 0.72 lux to 1.19 lux). The brightness of the source varied over the range from 1 - 2 nit to 120 nit.

Our experiments showed that, on variation of the display brightness from 1 - 2 nit to 120 nit, the CFF varied in the range from 16 to 30 cps. The hypothesis that the CFF depends on the configuration of the display was also confirmed. Thus, at a source brightness of 50 nit, the mean CFF for a display whose area was illuminated at 0.32 lux, was 24 cps. The mean CFF for a display of different configuration, with an illumination of 0.53 lux, was 28.3 cps.

Thus a decrease in the CFF can be obtained either by a reduction in the brightness of the light stimulus or by a decrease in the area of the illuminated surface, obtained by reducing the angular dimensions of the display or by changing its configuration.

We found a considerable individual variation in the CFF. Individual differences appeared most distinctly at minimum and maximum brightness of the display (coefficient of variation, 16%). At moderate brightness (50 nit), the /101 coefficient of variation was 14%.

#### ON THE MEASUREMENT OF SIMILARITY IN GRAPHIC IMAGES

# V.G.Stepanov (Moscow)

In this paper, the author discusses the measurement of the degree of similarity of graphic images (advertisements or posters) with various amounts of information. The subjective-statistical estimations of the degree of similarity were used to determine the weighting factors in the formula for evaluating similitude, proposed by V.A.Makhonin at the conference "Man and Automatic Machine" (December, 1963). The paper gives the experimental data.

# DEPENDENCE OF THE PERCEPTION OF ELECTRONIC DIGITAL INDICATOR READINGS ON THE ILLUMINATION OF THE INDICATING PORTIONS

# A.A.Krylov (Leningrad)

The use of electronic digital measuring devices as data sources on control desks is becoming widespread. The principal feature of such devices, with respect to perception of their readings, is the fact that they display a luminous colored image of the digits. In one type of such devices, special multi-plate tubes are used, with plates in the form of the digits from 0 to 9. The image of a given digit is obtained when the corresponding anode begins to glow. In devices of another type, the images of the digits are produced by the lumines-

cent glow of certain isolated parts (segments) of a phosphor. In laying out the electronic digital indicators on the instrument panels of control desks, the question naturally arises as to the illumination levels at which the indicating portions offer the most favorable conditions for visual perception of their readings. We discovered no papers on this problem in the USSR and foreign literature available to us.

In our studies we determined the rate and accuracy of perception of the readings of digital indicators using phosphors or vacuum tubes with the /102 indicating portions illuminated by incandescent bulbs or by VS fluorescent bulbs. The illumination levels in both cases were established at 1, 20, 50, 100, 200, 300, 450, 550 and 600 lux. Our studies established that the readability of phosphor-coated and vacuum-tube digital indicators depends on the ratio of the brightness of the fluorescent digits to the illumination of the indicating portion, and also on the spectral composition of the light radiated by the indicator digits and by external light sources. In perceiving the readings of the tube indicator, with the digits glowing orange-yellow at a brightness of about 85 nit (IN-1 tube) and of a fluorescent indicator (ZhVZ-012-005) with blue-glowing digits and a maximum brightness of about 11 nit, visual discrimination was possible at illumination levels to 600 lux, on account of the color contrast between the illuminated figures and the background (the surface of the indicating portion). At the same time, favorable conditions for visual perception of the readings were established at illuminations of the indicating portions of the devices considerably lower than those at which discrimination of the digits was still possible. For example, the subjects were able to perceive the instrument readings with maximum speed and accuracy and without eyestrain. at an illumination of the indicating portion of the fluorescent indicator not higher than 100 lux for incandescent bulbs, and not higher than 50 lux for the case of BS fluorescent bulbs. For a vacuum-tube indicator, when illuminated by incandescent bulbs, the perception of the readings without eyestrain was possible at an illumination not higher than 100 lux for the indicating portion. and not higher than 200 lux for the BS fluorescent bulbs. These differences are explained by the fact that the spectral composition of the radiation from the digits on the phosphor-coated indicator were close to the spectral composition of the light from the fluorescent bulbs, whereas the spectral composition of the radiation from the digits of the vacuum-tube indicator were closer to the spectral composition of the radiation from the incandescent bulbs. For this reason, owing to the higher color contrast between the illuminated figures and the background, perception of the readings of the fluorescent-screen indicator without eyestrain was possible at higher illumination levels of the indicating portion when incandescent bulbs were used; for the tube indicator, this was possible when the indicating portion was illuminated by BS fluorescent bulbs. It should be noted that, on reducing the brightness of glow of the figures on the fluorescent indicator, the conditions for the visual perception of the readings became relatively favorable at illumination levels considerably lower than those given above.

Consequently, electronic digital devices can be successfully used on instrument panels in combination with screens of cathode-ray tubes whose signals are better perceived at low illumination levels and in combination with pointer instruments, provided that the illumination of the indicating portions does /103 not exceed the above levels.

### ENTROPY METHOD FOR ESTIMATING THE ACCURACY CLASS AND SCALE DIVISIONS OF CONTROL-MEASURING DEVICES

1 1 1

# V.I.Nikolayev (Leningrad)

The instrumentation used in shipboard installations deviates considerably in scale design and in principal accuracy characteristics from the requirements that should be maintained in view of the character of the processes taking place in the installation and the activity of the operator in controlling these processes.

This paper formulates the general requirements for instrumentation based on the entropy method of analysis of the control circuit, including an operator and a real controlled object.

The circuits of operative control of the temperature of superheated steam of a boiler and the steam pressure in front of the valves of the main engine are considered.

Using experimental estimates of the traits of the operator, the author determines the principal characteristics of the device and shows methods of decreasing the load on the operator and of improving the wiring diagrams of the individual control circuits.

### ON THE RELATIONSHIP BETWEEN THE STRUCTURES OF THE SENSORY AND MOTOR REGIONS IN CONTROL OPERATORS

# L.M. Vekker and Ye.N. Surkov (Leningrad)

The specific quality of control operations as a special case of work generally depends to a considerable extent on the peculiar character of the relationship between the structures of the sensory and motor regions under the conditions of the operator's work. For this reason, the question of the sensorimotor structure of the control activity is of substantial importance both for the general theory of the psychic regulation of activity and for the problem in engineering psychology of establishing the optimum designs for control systems.

Our study was conducted by the method of a comparative analysis of the operations in the preparation of train routes under conditions of activity in systems with different relationships of the structures of the sensory and motor regions.

The characteristics of performance quality were the time indices and the character of the errors committed by the subject.

Our study consisted of two stages. In the first stage, we performed a comparative analysis of the process of preparing a train route under conditions of work at the control panel of a route-control interlocking system (RCIS), where the sensory and motor regions of the operator coincide both spatially and structurally, and under the conditions of work on a separate "removable" control panel, where, on the contrary, there is a spatial and structural difference between the sensory and motor regions.

The first stage consisted of two series of experiments. In the first series, problems of route preparation were solved by the same group of subjects, first on a separate control panel and then on a combined control panel of the RCIS. The results of this series show a sharp and statistically fully substantiated difference in the time characteristics of operation when the structures of the sensory and motor regions coincide (i.e., at the RCIS control panel). Operation under these conditions is almost three times as rapid, and the number of errors is considerably smaller. To exclude the effect of transfer and special training, the control panels, on which the given set of problems were /106 solved, were changed in random sequence in the next series of experiments. The difference in the characteristics of operation, in favor of the systems with coinciding structure of sensory and motor regions, was statistically even better substantiated.

Since, in working on a separate portable control panel with a breadboard arrangement of the controls, the sensory and motor regions are spatially separated and structurally different, the question arose whether the structure or

the localization was the decisive factor that slowed the operations by comparison with those at RCIS control panel.

To answer this question, we designed a third control panel spatially separated from the track diagram, but completely reproducing its structure, compatible in scale with the volume of the motor region of the operator. The second stage of our investigation consisted in a study of the operation in preparing the same routes as in the first stage, but working this time at this third control desk.

The results of this series showed a substantial difference between the characteristics of the operations on the two portable control panels (one with the same structure as the track diagram and the other with a different structure), whereas the speed of operation on the combined control panel and the portable control panel which structurally coincided with the track diagram showed no statistically reliable differences. Since, under the conditions of this control panel, there is a spatial separation although structurally the sensory and motor regions coincide, this result indicates the decisive influence of the factor of structural correspondence of the sensory and motor regions of the operator. This result is in agreement with the general principles of psychic regulation of activity and speaks in favor of the importance of taking this factor into account in the design features of indicating devices and control panels.

### EVALUATION OF CERTAIN SENSORIMOTOR COMPONENTS IN THE WORK OF A PILOT

# V.L.Marishchuk (Leningrad)

Modern work in the control of various mechanisms increasingly emphasizes intellectual operations with relatively low energy consumption and simplified motor components of occupational activities. This statement, however, is not absolutely valid for all occupations. For example, the activity of an aircraft pilot not only requires constant spreading and shifting of attention and making rapid decisions on difficult problems, involving widely disparate skill and knowledge, but also precise and accurate application of force to the controls and proper manipulation of the levers at correct amplitude and direction, since to each value of the motion of the aircraft control surfaces there corresponds a definite aerodynamic effect. It is well known that even a small excess force in depressing the pedal, producing a millimeter's excess deflection of the control stick, may cause a miss in aerial gunnery. In initial flight training noncoordination of the controls movements in the landing maneuver is one of the most frequent causes of failure to obtain permission for solo flight. It is also important that almost every mental response of the pilot, connected with the control of the aircraft, finds its final expression in a manifestation of the motor functions and often in a coordinated motion of hands and feet.

For three years we studied highly complex sensorimotor reactions in pilot trainees and conducted various experiments with 637 subjects, examining each group four times (once in obtaining the original data and annually during the

3-year period of flight training).

A feature of the technique used was the distinct complexity of the motor component in the tasks to be performed. The subjects were thoroughly trained in the meaning of nine different signals and then were exposed to their combinations, in response to which the corresponding coordinated and compatible movements of hands and feet were to be performed. The results of such response reactions were evaluated as the speed of action of the subject. The device used in the experiments was arbitrarily named "Avdiv", and carried the aircraft controls and several sources of visual and acoustic signals. We recorded the reaction or response time, the compatibility of the forces applied to the pedals, and the errors in motion coordination and in decisions taken.

The resultant data on the mean reaction time were distributed over a wide range from 865 msec without errors to 3117 msec with 50% of wrong reactions.

Not over 20% of the measurements, however, were in the extreme range (less than 1100 and more than 2000 msec) and the total variance of the data is small ( $\sigma$  = 278.4 for M = 1590) which attracts particular attention to the extreme results.

The force applied (in spite of preliminary training), when the required force was 3 kg, was as high as 50 kg in occasional subjects. The reaction /108 time was determined by the sensory and mainly by the central moment of reaction and by the accuracy of response to the maximum variation in the motor component.

The results of the investigation, characterizing the quality and speed of actions, largely predetermined the later success of the subjects in initial flight training. The longer the motor reactions took on the "Avdiv" tester and the more incompatible they were, the more time and means were required for the practical flight instruction and the more often did cases of failure in flight occur. The coefficient of correlation between the reaction time and the number of training flights before the first solo flight, over various years of the investigation, ranged from 0.3 to 0.4.

The quality of "speed in action" studied by us proved very dynamic. Thus, already after completing initial flight training, the average results of our experiments improved by 14.3% over the initial values; after the period of theoretical instruction there was a slight decline (by 2.5%) but, after mastery of a new aircraft type, the indices again improved, this time by 5.5%. This rise in the indices, characterizing the sensorimotor components of activity, indicates in this case a positive transfer of skill acquired in flying practice to the activity of the subject, as well as a general improvement in the motility of the nervous processes of the pilots in their work. The indices of the study, characterizing speed in action, showed a certain interrelation with the results of the hundred-yard dash, the hundred-yard swim, and the results of special physical exercises in motor coordination and were inversely proportional to the results of exercises that involve static endurance.

### ANALYSIS OF THE SENSORIMOTOR ACT IN PILOTING SHIPS WITH HYDROFOILS

# E.A.Belkina (Moscow)

The development of ships with remote-controlled hydrofoils will result in a change in the function of the helmsmen. The increased speed of the boat limits the time that can be spent on search and perception of the navigational situation (sensory process) and on the necessary motor reaction.

Particularly great demands on speed and accuracy of signal perception and on stability of vigilance of the helmsmen are made at night, when the warning /109 signals for channel direction and channel width are signal lights that are perceived as points on the visual threshold.

To investigate the perception of light signals within a limited observation time, we designed an experimental apparatus to simulate navigation at night. On a recording device, we recorded the time of search for and perception of a signal light, the latency period of motor reaction, and the accuracy and speed of performance of the motor action in changing the "course of the ship".

The perception of white point sources of light were studied against a background of brightness  $10^{-6}$  nit or  $6 \times 10^{-2}$  nit at the limits of a search field of  $30^{\circ}$ , at various intensities of the signal light.

The total time spent by the helmsmen on search and perception, together with the latency period of the motor reaction, was shorter against the dark background than against the bright background. The number of erroneous responses and undetected signals, as well as the time of performance of the motor action, were greater when the signals appeared against a dark background.

In the presence of extraneous point sources of light within the field of vision, the total time of search, perception, and latency period of the motor reaction increased in the case where the signal lights were near the threshold level. With increasing intensity of the light signal, the overall time became shorter.

In the performance of work in steering a ship with simultaneous observation of a light signal, the threshold of light sensitivity increased.

On the ship "Raketa", we investigated the state of the visual functions of the helmsmen in night watches of varying duration. The visual acuity, the visual range, and the speed of the visuomotor reaction decreased after only 3 - 4 hours on watch duty. After longer watches there were considerable changes in the functions examined.

For the purpose of improving the work of helmsmen, we submitted a recommendation to the Ministry of River Transportation to use a safety factor and parameters for the time of search, perception, and latency period of motor re-

action, necessary for calculating the light-signal navigational environment in piloting hydrofoil boats.

We suggested that the changes noted in the visual functions of helmsmen be taken into account in calculating the visibility of navigational markers.

# CONTRIBUTION TO THE QUESTION OF THE MECHANISMS OF PSYCHIC REGULATION OF THE ACTIVITY OF AN OPERATOR WORKING UNDER CONDITIONS OF TRACKING

<u>/110</u>

### V.M. Vodlozerov and B.F. Lomov (Leningrad)

The problem of psychic regulation of motor activity in work, which was one of the very first problems of industrial psychology, has now become one of the most important problems of engineering psychology. Knowledge of the laws and mechanisms of regulation of the behavior of an operator working under various conditions is necessary to solve such problems as: optimum distribution of functions between man and machine in control systems, development of the psychological principles of designing indicators and controls, optimum relation between sensory and motor regions, etc.

Of particular interest in this problem is the study of activity directed toward the solution of continuous perceptual-motor problems (in retary pursuit tests).

The conditions for an effective performance of the operation of tracking are:

continuous evaluation of the instantaneous state of the signal; continuous matching of the motion to the varying states of the signal; prediction of the future variation of the signal; operative readiness to reorganize motor behavior.

The set of all these conditions defines the dynamics of the operator's actions and of the mechanisms of their control.

The activity of a human subject was experimentally studied while he was performing the operations of tracking a one-dimensional visual signal (a target being displaced along a straight line at constant speed). The task of the subject was to move a pointer over a handle (or handwheel) in such a manner as to keep it continually trained on the target.

An analysis of the experimental data showed that, in the first stage of tracking, a series of discrete reactions was performed in response to the variation in the signal position, first relative to its initial position and then relative to the pointer. The so-called external circuit (eye - hand) plays the leading role in the control of motion in this stage. The visual system performs the function of measuring the displacement of the signal, while the kinesthetic system measures the displacement of the hand. On the basis of commensurable visual and kinesthetic signals, the ratio of the values of displacement of the signal and hand ("the transfer number") is found.

In the pursuit test, the controlling visual pattern is reorganized. As a result of accumulation and averaging of mismatched signals during a certain time, it becomes possible to estimate the target speed. From a control of /lll the hand motions according to position, the subject passes to their control according to speed. This, in turn, ensures inclusion of the mechanism of visual extrapolation in the control circuit.

The reorganization of the visual pattern creates the conditions for activation of the so-called internal control circuit (the kinesthetic system hand/hand motorium). This causes the movements to become continuous and smoother. The number and duration of the pauses are substantially diminished; the magnitude of the errors decreases, and the "time lag" is overcome. The basic function of the visual system from then on becomes supervision only.

The motor component of the action of tracking includes the greater part of all movements: orienting, measuring, executory, corrective, and adaptive.

The internal control circuit ensures an optimum combination, at each given moment, of the above forms of motion by various elements of the hand, and their mutual transitions. During tracking, the hands are in a state of "dynamic equilibrium", permitting the created reactive forces to be compensated at maximum speed. This is one of the most important conditions of operative readiness for reorganization of motor behavior.

#### A FEW CHARACTERISTICS OF AN OPERATOR'S WORK IN TRACKING AND PURSUIT OF A ONE-DIMENSIONAL SIGNAL

# V.M.Vodlozerov (Leningrad)

The movements of the hand during the process of tracking and pursuit of a uniformly moving signal are discrete and irregular. The discreteness of the movements of the hand is manifested with particular distinction at low target speeds (1 - 4 mm/sec): these break down into several partial movements, interrupted by a considerable number of intermotion intervals. The irregularity of the tracking movements is expressed in the fact that they differ in speed and duration indices. If their speed is related to the target speed, then all these movements can be subdivided into three forms: motion at a speed 1) greater than the target speed (G-motion), 2) less than the target speed (L-motion), 3) equal to the target speed (E-motion). With increasing target speed, the number of intervals decreases sharply; at the highest speeds used in our experiments (8 - 10 mm/sec), such intervals are generally observed only in the first 2 to 3 sec. The number of L-motions, on the other hand, increases sharply. with increasing target speed and increasing tracking time, the motion of the hand becomes continuous but still remains irregular. It may be assumed that the change in the character of motion is due to a reorganization of the mechanism of its psychic control.

Two types of operation must be distinguished in the work of an operator in the pursuit of a uniformly moving signal: the transient (dynamic) and the steady state.

The characteristic features of the transient state are: a) Existence of a latency period (a delay time of the reaction at the beginning of the signal displacement). Experiments have shown that, with increasing signal speed, the delay time decreases from 0.65 to 0.25 - 0.26 sec, i.e., it approaches the time of simple sensorimotor reaction. b) Change in the indices (speed and duration) of G- and L-motions. The mean speed of G-motions, in decreasing, approaches the target speed. This decrease is particularly pronounced by a factor of 2 - 2.5, at low target speeds (1 - 2 mm/sec), while at higher target speeds (6 - 10 mm/sec) this factor is only 1.3 - 1.4. The mean speed of the L-motions at target speeds of 1 - 4 mm/sec is approximately constant but increases slightly at higher target speeds and approaches the target speed. The mean duration of the G-motion increases. The mean duration of the L-motion is variable, especially at the beginning, but in the course of the tracking becomes somewhat stabilized at about 0.26 - 0.28 sec; c) Decrease in intervals. At target speeds of 1 - 6 mm/sec the mean number of intervals decreases (by a factor of 2 - 3) to some approximately constant level which, at target speeds of 1 mm/sec, is 2-3 times as great as at target speeds of 4-6 mm/sec. The mean duration of intervals at target speeds of 1 - 2 mm/sec decreases from 0.5 - 0.4 sec to 0.28 - 0.30 sec, and at target speeds of 4 - 6 mm/sec from 0.36 - 0.40 to 0.25 - 0.22 sec: d) Decrease in mean value of mismatch signals. Values with the "-" sign (undercontrol) and "+" sign (overcontrol) decrease to a certain approximately constant level. At target speeds of 1 - 2 mm/sec, the error of the lag and lead time decreases from ± 0.65 to ± 0.30 - 0.25 sec. At target speeds of 6 - 10 mm/sec the error of the lag time decreases from 0.28 - 0.26 to 0.13 - 0.10 sec, and the error of the lead time from 0.25 - 0.20 to 0.05 -- 0.04 sec.

The duration of the transient state of operation is about 2-3 sec.

Two principal forms of transients are distinguished: oscillatory with overshoots (cvercontrol) and oscillatory without overshoots.

An analysis of the data obtained in our experiments shows that, at low target speeds (1 - 2 mm/sec), the former form predominates and at higher target speeds (6 - 10 mm/sec), the latter.

<u>/113</u>

The steady-state regime of operation is characterized by the relative stability of the indices of both G- and L-motions; at the higher target speeds they are more stable. The mean duration of G- and L-motions at target speeds of 1 - 10 mm/sec is approximately constant at 0.30 - 0.32 sec. With increasing

target speed the mean speed of hand motion  $\frac{V_{mot}G + V_{mot}}{2}$  approaches the tar-

get speed and, at target speeds of 8 - 10 mm/sec, becomes approximately equal to the target speed. The steady-state error of lag time decreases from 0.30 to 0.09 - 0.10 sec as the target speed increases from 1 to 10 mm/sec, while the lead error decreases from 0.30 to 0.03 - 0.05 sec.

In the steady-state regime, in spite of the low accuracy of tracking, the activity of the operators is characterized by high dynamic stability and reliability, obviously due to the peculiarities of psychic control.

Evidently, at low target speeds the correcting and supervisory function is accomplished mainly during the intervals whereas, at higher target speeds, this is done mainly during the performance of the motion, connected with the change in the control methods. At low target speeds (1 - 2 mm/sec) the control is accomplished primarily according to the magnitude and sign of the mismatch signal, i.e., from the sight position relative to the target (positional tracking). With increasing rate of displacement of the signal and increasing tracking time (in steady-state operation), control by velocity and acceleration (velocity tracking) becomes more and more important. Control by velocity assumes the averaging of the velocity of the hand motions.

1 1 1 1111 1

Transition from one method of control to the other causes a reconstruction of the operation of the principal elements of the reflex arc primarily of the assigning and comparing mechanisms.

#### METHOD OF PSYCHOLOGICAL STUDY OF AN OPERATOR'S ACTIVITY

Ye.A.Mileryan (Kiev)

In this methodology we used a specially designed setup, consisting of a subject desk and an experimental desk. The subject's desk consists of a vertical and an inclined panel. The vertical panel is divided into two parts, with a translucent screen on the right-hand part over which sweeps a luminous white spot whose trajectory is determined by the shape of a curvilinear contour placed behind the screen. The speed of this spot is determined by the speed of displacement of a slotted strip which scans the image. A special device permits the experimenter to vary the scanning speed smoothly within wide limits. In addition to the white spot moving along the assigned contour, the subject also sees on the screen a red spot which he can displace over the screen at varying speed. The motion of this spot is remote-controlled by actuating a lever on the inclined panel. By shifting the left-hand lever, the subject can displace his spot upward or downward, and by operating the right-hand lever, he can displace it to the right or left.

Thus, by simultaneously operating both levers, the subject can force his spot to move in any direction on the screen.

Alongside the translucent screen on the vertical panel of the subject's desk are six images of curvilinear contours. Under each of them is a tumbler switch. These tumblers are used to determine the time required by the subject to identify the shape of the trajectory of the spot on the screen.

In addition, the inclined panel of the control desk carries two rows of keys, ten in each row. The keys are numbered from one to ten. The upper row is labeled "vertical" and the lower, "horizontal".

In working at the control desk the subject must continuously follow the displacement of the luminous white spot and, by actuating the control levers, direct the motion of his own red spot so as to make it coincide with the white spot.

As he performs the task of tracking pursuit, the subject must also determine the law or strategy of motion of the white spot on the screen. In guessing this strategy he must orient himself by the sample trajectories placed alongside the screen. The time at which he recognizes the strategy controlling the motion of the spot is objectively recorded by his closing the tumbler switch below the corresponding sample trajectory.

The translucent screen is provided with a coordinate net. By means of this net, the subject must, at given moments, determine the coordinates of the moving spot and record his result by simultaneously depressing the corresponding keys.

The apparatus records the number of correct and erroneous reactions of the subject in determining the coordinates of the moving spot. The pulse counters on the experimenter's desk record the following indices of the subject's work:

1) duration of the programs; 2) tracking time, i.e., the time during which /115 the subject superposes the motion of "his" spot with the motion of the test spot, i.e., the white spot; 3) total number of readings of the data coordinates during the experiment; 4) number of correct readings of the coordinates; 5) time required for correct identification of the trajectory shape or the strategy of motion of the white spot on the screen.

An experimental check of this method (on 23 subjects) permitted the following preliminary conclusions:

- 1) At the beginning of the work, the subjects commit errors in recognizing the shape of the spot trajectory, but with increasing practice their perception becomes increasingly adequate and takes a shorter time. At the end of the training (from 20 to 80 repetitions) the overwhelming majority of the subjects identified the form in 25% of its development time. In four subjects, we observed an extraordinarily rapid recognition of the trajectory shape under conditions of inadequate information.
- 2. Recognition of the form depends on the rate of its development. There are optimum target speeds, at which an adequate idea of the trajectory of the spot is more readily obtained. A slow motion of the spot and an exceedingly rapid motion both cause considerable difficulties in recognizing the form. For adequate perception and recognition of this form there is presumably some definite optimum of information in unit time. The described technique permits solving the question of that optimum.
- 3. During the study, the regulating role of the form-qualities in the accomplishment of the subjects' functions of control and determination of the strategy of their actions was distinctly manifested. Usually, after recognition of the form a reorganization of activity relative to regulation and control is noted.

Guided by a distinct concept on the trajectory of the white spot, the subject usually passes to the strategy of anticipation. The red spot begins to move ahead of the white spot. Because of such a prediction of future position the subject obtains a definite time advantage. In this case, the index characterizing the tracking time is significantly increased. At the end of the

training period, 27% of the subjects were able to place their spot with a lead on  $\frac{1}{4} - \frac{1}{2}$  of its trajectory.

4. The subjects had considerable difficulty in giving information on the coordinates of motion of the spot at the beginning of the training period (60 to 75% of errors). At the end of the training, however, the total number of errors did not exceed 20 - 25%. Our studies showed that one of the causes of the errors committed by the subjects was the irrational arrangement of the keys.

The resultant experimental data permit the assumption that this methodology can be used in occupational selection tests of operators.

### STUDY OF AN OPERATOR'S ACTIVITY IN TRACKING AN OBJECT OF VARYING ILLUMINATION

<u>/116</u>

S.N.Leviyeva (Leningrad)

Experiments on the activity of operators are conducted by most USSR and foreign investigators with tests on tracking the change in position of a given object.

The study of an operator's activity in tracking the varying illumination of an object is also of a certain interest.

In the present investigation the task was to track a discrete change in signals combined into certain series, the operator being given unlimited time. The main portion of the experimental setup consisted of a system of two screens, the illumination of one of which was varied by the experimenter and that of the second, by the operator. The test subject was asked to match the illumination of the second screen with that of the first The program and changes of illumination performed by the operator was recorded on the strip chart of an oscillograph.

The activity of equalization was studied as a function of:

- a) the absolute strength of the signals, i.e., the absolute illumination level of the screen. The signals were given in three series, from 20 to 50 lux, from 115 to 225 lux, and from 185 to 300 lux;
- b) the magnitude of the drop between two successive signals (a drop of +10 lux between the signals of 40 and 50 lux, and a drop of -40 lux between the signals of 300 and 260 lux).

The following characteristics of the tracking activity were analyzed:

- a) "latent reaction period", i.e., the time from the beginning of the change in signal to the beginning of motion of the operator's hand;
- b) "motor reaction time", i.e., the time required by the operator for making the motions leading to equalization of the illumination of his screen

with the illumination of the reference screen;

- c) "evaluation time", i.e., the time during which the operator rates the result of his actions (on starting the evaluation, he must, according to the instructions, say "ready");
- d) "equalization time", including the "latency period", the "motor reaction time", and "the evaluation time";
- e) "accuracy of equalization", i.e., the degree to which the illumination of the operator's screen corresponds to the illumination of the reference screen. The preliminary experimental data permit the following conclusions:

The shortest latency period corresponds to reactions to a screen illumination of 20 - 225 lux, the longest period to an illumination of 185 - 300 lux. The curves of the length of the latency period, plotted against direction /117 (according to the signs "+" or "-"), are almost mirror images of each other.

Consequently, the absolute value of the difference rather than its direction influences the magnitude of the latent reaction period.

The equalization time increases slightly with the absolute value of the signal. According to our data, this time does not depend on the absolute value of the illumination of the signals nor on the "drop" between them but rather on other conditions (for example, training).

The accuracy of the tracking depends largely on the absolute value of screen illumination. Thus, the thresholds of discrimination are relatively low for illuminations from 20 to 135 - 180 lux and increase considerably from 135 to 185 lux up to 300 lux.

The magnitude of the latency period and the accuracy of tracking are influenced not only by the absolute value of the signal and the illumination decrement, but also by the position of the signal within the series of other signals.

### THE EFFECT OF PAIN IMPULSES ON THE COURSE OF THE TRACE PROCESSES IN THE HUMAN MOTOR ANALYSOR

# L.P.Pavlova (Leningrad)

The fact that muscular working ability is enhanced by mobilization of the will and intensification of motivation is widely known in labor and athletic practice. However, the physiological mechanism of this phenomenon remains largely unknown. Up to now there has been the assertion that painful impulses, so to say, whip up the exhausted muscles and therefore only temporarily enhance the ability to work, while at the same time the fatigue is becoming more intense. This contradicts conventional knowledge according to which the cerebral cortex plays a positive trophic role and the centers exert a deparabiotizing influence on the periphery (L.L. Vasil 'yev, 1954).

In studying the trace processes in the kinesthetic receptor, we believe to have discovered certain mechanisms of action of pain impulses on the human kinesodic system.

Our method of evaluating trace reactions in the motor analysor was published under the title "Methodology of a Weak Focus of Excitation" (Metodiki slabogo ochaga vozbuzhdeniya, L.Pavlova, 1962). The subject performs so-called background movements, automatic weak flexion of the index fingers of the right and left hand, performed without load. The background movements do not tire /118 the subject and have a testing quality since they are able to vary in amplitude and rate in accordance with the current dynamics of the nervous processes in the brain, under the influence of stronger stimuli arriving at the kinesthetic and other receptors. Thus, after work on a manual ergograph for a certain time, periods of enhanced and diminished background activity were observed. A special check showed that these periods correspond to phases of enhanced and diminished capacity for work (exaltation and refractoriness) of the nerve centers.

By gradually increasing the work stimulus, by applying larger loads and a greater number of movements, we discovered four known successive types of trace reactions (N.V.Golikov, 1950): exaltation aftereffect, inhibition following excitation, exaltation following inhibition, and, finally, inhibitory aftereffect.

The last and fourth type of trace reaction, as shown by our experiments, is observed only after work causing fatigue (a decline in the magnitude of the contractions); in this case, the period of exaltation manifests itself first in the nerve center that had not worked, i.e., in the symmetric muscle, and only after the lapse of a certain time in the center that had worked. This fact is novel and helps to interpret the mechanisms of "active rest" according to Sechenov, with alternation of the working hands. Our experiments showed that the higher the functional level of the motor apparatus, the slower will be the transition of the first type of trace reaction to the succeeding types, and the later will the fourth type appear on gradual "increase in stimulation".

We found that under conditions of work with a painful stress (involving the highest cortical level or the "dominants of vigilance"), the observed types of trace reaction appear earlier than in the absence of painful stress, after the same number of finger flexions.

Consequently, it seems that the highest cortical level of regulation increases the fitness for work by exerting a positive-trophic influence on the motor apparatus. In this case, we found a stronger influence on the centers of the right hand than on the centers of the left, which corresponded to the right-handedness of our subjects.

At greater cumulative fatigue, the painful stress induced a more complex manifestation, expressed in a prolonged alternation of the trace exaltations, now on one side and now on the other (for 10 - 20 min). The initial onset of trace exaltation, under these conditions, however, was always observed on the side of the limb that had done work, i.e., opposite to the manifestation of exaltation in the fourth type of trace reaction, which usually appears after fatiguing work performed without involving a painful stress.

The study of trace reactions during the process of overcoming the /119 "dead point" in work on the ergograph gives grounds for believing that this process of active overcoming of fatigue takes place by means of alternate work, now on a lower level of regulation, now on the higher level connected with the painful stress.

The positive role of the highest level of regulation in the integration of the working rhythm is that, after the painful stress, the onset of exaltation follows on the same side as the center that had been doing work, while the subsequent working movements will obviously occur during the period of enhanced lability of the centers.

#### ASYMMETRY IN THE MANIFESTATION OF MUSCLE SENSE

Ye.P.Il'in (Leningrad)

Kinesthesis, or proprioceptive sensitivity, is very important for a correct evaluation of many spatial, temporal, and dynamic factors. In connection with the existence of right- or left-handedness in man, the question arises whether the proprioceptive sensitivity of both hands is the same. This question has not yet been finally decided. Some authors believe that when a right-handed person estimates the weight of an object and determines its dimensions, it is not the right hand but the left that is leading (Bauer, Anan'yev). Others hold that there is a right-sided asymmetry in estimating weights (Birflit) and perceiving space (Leeb, Lomov, Bogdanova and others). Still others refute both types of conclusion (Chapanis).

The contradictory statements in the literature led us to make a particularly detailed study of the asymmetry of muscular sensitivity. In our experiments we studied the ability of both hands to estimate the weight of objects and to reproduce prescribed forces and amplitudes of motion. Accordingly, in each of three series of experiments, objects of various size (small, medium, optimum, and large) were shown the subjects for estimation and reproduction. Each object was placed ten times on each hand. About 40 subjects took part in the experiments.

The results of all three series of experiments were the same.

- 1) For each hand there is an optimum size of the object to be estimated, at which the estimate is most accurate. The optimum absolute size of the object is greater for the dominant hand. The difference in the size of the optimum object corresponds to the value of the constant asymmetry of the hands, which is a reflection of the asymmetry in the strength of excitation of the centers of the right and left hands.
- 2) For the size of the object to be estimated, optimum for each hand, there is no asymmetry in the manifestation of kinesthesis since both hands give the same values of the errors on reproduction.
  - 3) The asymmetry of muscle sense manifests itself most clearly whenever

one of the hands is subjected to more favorable or less favorable conditions for reproduction of the estimated object. This happens each time an object is placed in both hands, that has the same absolute size which, for one hand, is closer to the optimum size but, for the other hand, is further away from it.

In this case, the sign of the asymmetry (right- or left-hand) depends on the side toward which the object to be estimated deviates from the optimum size: If the size is greater than optimum, the asymmetry will be right-handed (the error will be less on the right hand) and if the size is less than optimum, the asymmetry will be left-handed (the error will be less on the left hand).

The degree of asymmetry depends on the extent to which the size of the exhibited object differs from optimum (directly proportional).

4) At small size of the objects, we observed an overestimation and, at large sizes, an underestimation. This can be attributed to the tendency of the central nervous system to maintain optimum operation and thereby to reflect adequately, by means of kinesthesia, the spatial and dynamic characteristics of the applied stimuli.

#### THE EFFECT OF VARIOUS FACTORS ON HUMAN REACTION TIME

G.F.Plekhanov, V.V.Vedyushkina, L.P.Nagayev and Ye.I.Osinskaya (Novosibirsk)

During life, and also in his work, man is compelled to react constantly and in a definite manner to stimuli of the external world. In many cases, this reaction must be extremely rapid (work of a pilot, a helmsman, an operator, or even that of an ordinary pedestrian, etc.). The measurement and estimation of human reaction time in response to some stimulus or signal is therefore not only of theoretical significance but also of practical importance. The factors influencing the reaction time may be subdivided into internal and external. The former are connected with the state of the organism, the latter with the character of the stimulus and also with external conditions which have a direct or indirect influence on the human organism and can be classified as follows:

### 1. Human Subject.

- a) Individual traits.
- b) State of health.
- c) Age.
- d) Sex.
- e) Training.
- f) Fatigue.
- g) Concentration.
- h) Effect of drugs.

#### 2. Stimulus

a) Energy content of the signal.

<u>/121</u>

b) Form of the signal.

c) Magnitude of the signal.

#### 3. Conditions.

a) Specific noise (of the same energetic nature).

b) Nonspecific noise (environment, distracting stimuli).

- c) Meteorological factors (atmospheric pressure, cloudiness, wind, etc.)
- d) Cosmic factors (solar activity, state of the ionosphere).

The reaction time was experimentally measured under various conditions, mainly under the action of acoustic signals. Over 5000 measurements were made in all. The author demonstrates the relation between most of the above factors and the reaction time. The material is presented in the form of summary tables and graphs.

### EFFECT OF ATTITUDE TOWARD A TASK ON THE SPEED OF A SIMPLE SENSORIMOTOR REACTION

## A.S.Yegorov and B.N.Yakovets (Leningrad)

One of the measures for fitness for work of a human subject is the speed of his simple sensorimotor reaction. However, "it is impossible to judge the fitness for work without taking account of the activity of attitude and its positive or negative character" (V.N.Myasishchev). From this proposition it follows that it is possible that the speed of a simple motor reaction depends on the subject's attitude toward the task or stimulus to which he is reacting.

Factual data by A.Ye.Ol'shannikova confirm, to a certain extent, the existence of such a dependence. These data indicate that the reaction to a weak stimulus, if it is sufficiently significant (such as an emergency signal), may be shorter than to a strong but less significant stimulus.

In this connection, it seemed useful to make a more detailed study of the dependence of the speed of a simple reaction on the attitude of the subjects toward the task.

Twenty students of the P.F.Lesgaft GDOIFK (Institute of Physical Culture) were the subjects used for the study. These were asked, by instantaneously removing their finger from a telegraph key, to react to the flash of an orange-colored bulb.

The study was conducted in four series: 1) training; 2) test; 3) training; 4) test - competitive. Each series consisted of 20 reactions.

The features of the series were as follows:

The first series of reactions, as the subject was told, had the object of attaining the best and most stable reaction speed possible, so as to train him

for the actual test series. The subject was informed of the time he took for each reaction.

The second series was run as the test proper. From its results we made an official estimate of the ability of the subject to react rapidly.

At the end of the second series, the subject was told that his mean reaction time was only satisfactory by comparison with the results of certain other subjects of the same athletic qualifications as he, and that he had to be retrained (third series) so as to perform still better in the fourth series.

From this difference in the content and significance of the tasks, we obtained indications of the differing attitude of the subjects toward the task in the different series of experiments.

The results are given in the Table.

DEPENDENCE OF THE REACTION TIME ON THE ATTITUDE OF THE SUBJECTS TOWARD THE TASK

	Reaction Time in Sigmas	
Series	x	σ
I	270	40
II	240	45
III	270	48
IV	230	38

The differences between the arithmetic means of the series are reliable, with a confidence index of 0.05.

These data indicate the dependence of the reaction time on the subject's attitude toward the task which may be explained from the viewpoint of the attitude psychology (V.N.Myasishchev) and Pavlovian physiology (the law of the strength of the stimulus and the theorem on the charge of the nerve centers).

The results of the study indicate the necessity of evaluating the subjects' ability for rapid reaction on the level of significant attitudes.

# SPEED OF A SIMPLE SENSORIMOTOR REACTION UNDER UNEXPECTED DELAYS AND ACCELERATIONS IN THE TEMPO-RHYTHM OF APPLICATION OF A STIMULUS

<u>/123</u>

#### A.S. Yegorov and B.N. Yakovets

This study was likewise conducted on 20 students of the P.F.Lesgaft GDOIFK. The experiments were run in two series of 30 reactions each.

The program of application of the stimuli in the first series was as follows: The average interval between stimuli was 4 sec. Stimuli Nos.11, 18, and 29 were applied with a 6-sec interval, followed by Nos.12, 19, and 30 with a 2-sec interval. The second series differs from the first only in changing of the sequence of the unexpected delays and accelerations. The accelerations were first applied, and then the delays.

The Table shows the results.

### SPEED OF REACTION WITH UNEXPECTED DELAYS OR ACCELERATIONS IN THE TEMPO-RHYTHM OF APPLICATION OF THE STIMULI

No. Time Characteristic of Application of Stimulus	Time Characteristic of	Reaction Time in Sigmas	
	x	σ	
1	Rhythmic	240	42
2	Delayed	290	98
3	Accelerated	350	245

The differences between the arithmetic means (x) of the reaction times with a rhythmic application of the stimulus and with delays and accelerations in the application of the stimulus are statistically substantiated, with a confidence index of 0.05.

It will be seen from the Table that the reaction time to unexpected delays and accelerations is considerably greater than the reaction time to stimuli applied in rhythmic order. In this case, the increase in reaction time is greater in cases of acceleration and less in cases of delay in application of the stimulus.

This fact can hardly be explained by the influence of orienting reaction to a novel situation (factor of unexpectedness) in view of the fact that both the delay and the acceleration in application of the stimuli were equally unexpected for the subject and were therefore of equal significance for the orienting reflex.

On the basis of modern data on electrophysiology of the adoption of a rhythm (P.I.Gulyayev, F.K.Zhukov, K.B.Sclogub, and others) it may be assumed that during reaction to a rhythmic stimulus, the corresponding rhythm is elaborated in the dynamics of excitation and inhibition, stress and relaxa— /124 tion, which may be imagined in space in the form of a sinusoidal wave having its crest at the moment of action of the stimulus and its trough somewhere in the middle of the interval between the actions of the stimuli. In case of a sharp acceleration in the tempo-rhythm of application of the stimulus, the instant of action of the stimulus may coincide exactly with the instant of dip in the wave, i.e., at the instant of least readiness of the system for reaction. Hence the maximum reaction time.

In delays, however, the absence of the stimulus at the expected instant causes an arbitrary delay of the reaction and simultaneously acts as a factor of nonreinforcement of the given rhythm. This leads to its damping in the form of a slow decline of the wave of excitation, so that the action of the delayed stimulus still blocks the end of this wave and the reaction proceeds on a more favorable physiological background than on premature action of the stimulus.

Of course the above-expressed ideas require experimental electrophysiological verification.

### CHANGE IN THE TIME COMPONENTS OF A COMPLEX REACTION UNDER THE INFLUENCE OF UNEXPECTED NOISE

Yu.Ya.Kiselev (Leningrad)

Sensorimotor reactions are usually studied under conditions where no external causes interfere with the subject's perception of certain signals and his reaction to these signals according to the experimenter's instructions. Under actual conditions of work, however, the signals that induce some level of reaction in man are often accompanied in time by extraneous unexpected stimuli which, to some extent, affect the reactions to the signal.

In this paper the author discusses the results of an experiment staged with the object of studying the effect of unexpected noise on the speed and accuracy of a kinesthetic reaction.

The study was conducted with a device which permitted, to within an accuracy of five thousandths of a second, to determine the total reaction time and the time of its latent and motor components.

The subject was shown in "random" sequence four signals (two of them positive and two inhibitory). On receipt of the positive signal the subject made a movement of the right hand, previously overtrained and following a /125 strictly determined trajectory. This motion was transmitted to a movable device of the apparatus. On receipt of the inhibitory signal, the subject refrained from motion.

After giving the first 25 signals the experimenter began to accompany some of the next 25 signals by additional stimuli, which the subject did not expect. In the first series of experiments (38 subjects) these unexpected signals were a report from a starter pistol and the noise of an automobile siren, and in the second series (6 subjects) they were light stimuli, displayed on the same screen and having the same intensity as the positive or inhibitory signals covered by the instructions.

A workup of the results showed that the unexpected stimuli or noises, when applied simultaneously with the positive signals, exerted an inhibitory action on the motor reaction, especially when they were given for the first time.

Under the action of unexpected stimuli the total reaction time increased

by 35.2% on the average in the first series of experiments (from 750 to 1015 msec) and by 48.2% in the second series (from 745 to 1105 msec); the latency period increased by 44% (from 500 to 720 msec) in the first series and by 65.6% (from 480 to 795 msec) in the second series; the motor period increased by 18% (from 250 to 295 msec) in the first series and by 20.1% (from 265 to 310 msec) in the second series.

On repeated application of unexpected stimuli, the total reaction time increased by 3.3% (first series) and by 16.6% (second series); the latency period increased by 7% (first series) and by 21.9% (second series); the motor period decreased by 4% in the first series but increased by 5.1% in the second.

The considerable weakening of the inhibitory influence of extraneous noise in cases where the subject was repeatedly exposed to it can be explained by the fact that the slowing of the reaction is due not so much to the physical strength of the extraneous stimulus as to its unexpectedness. This is confirmed by the fact that the additional light stimulus applied in the second experimental series exerted even a somewhat greater inhibitory influence on the motor reaction as a whole and on its individual components than the extremely strong acoustic stimulus applied in the first series. This is connected with the close similarity of the parameters of the additional stimulus in the second series - intensity, color, position - to the prescribed signals, which makes it a high-intensity noise. For this reason, adaptation to such a stimulus is slower than to a strong stimulus which sharply differs from the significant one.

As late as 25 sec after initial application of the additional stimulus, its inhibitory action on the motor reaction still persists, especially in relation to the latency period. Twenty-five seconds after the second application of the additional stimulus, its inhibitory action is slight.

An unexpected collateral stimulus exerts an influence not only on the speed but also on the accuracy of a complex reaction. If such a stimulus coincides with an inhibitory stimulus, the response to this inhibitory signal was a positive reaction in 58.5% of the cases. In experiments in which no additional stimuli were applied, a disturbance of differentiation was observed in 19.2% of the cases, i.e., in only one third as many.

### ON CERTAIN PECULIARITIES OF HUMAN REACTION OF SELECTION UNDER CONDITIONS OF HYPOKINESIS

A.N.Kalinina and A.N.Kozlov (Moscow)

The operator as an element in a single "man - machine" system has various levels of ability. Significance of the signals in the process of perception, age differential, dependence of perception on the relative intensity of the signals and on their application rate, level of training, and many other factors all determine the state of the operator and substantially affect the speed of his reception of information. All these variables produce modifications of the dependence, established by Hick, of the selection reaction time on the amount of information received by the subject.

The purpose of this experimental study was to obtain certain characteristics of the influence of fatigue, produced by protracted limitation of the motor activity of the subject, on the speed of reception of information.

We studied the features of the selection reaction to light signals, with the subject in the horizontal position (confined to bed for 20 days). We also studied the sensorimotor component in the operator's activity. With this in mind, we recorded the reaction time and the motor reaction of the subject in the form of a mechanogram and an electromyogram. The simultaneous recording of both components of the motor reaction (mechanical and electrical) permitted us to follow the complex neurodynamics of the cortical processes of the subject, and to determine the degree of fatigue and fitness for work under conditions of hypokinesis.

The subjects were divided into "slower" and "faster", depending on the speed of motor response reaction prior to the state of hypokinesis. We found that, after the end of the period of confinement to bed, the speed of the response reaction of the subjects varied in inverse directions; in subjects with slower reactions, the speed of information perception increased, while it /127 decreased in the subjects with faster reactions. This phenomenon evidently depends on certain individual traits of the subjects, more specifically on the degree of equilibrium of their nervous activity.

These data confirm the inverse proportionality derived by Strollo, between the speed of reaction and the susceptibility to fatigue (1956).

CHARACTERIZATION OF THE MOTOR COMPONENT OF THE SENSORI-MOTOR REACTION TO SIGNALS FORMING A BINARY SEQUENCE

### V.A.Bodrov (Leningrad)

One of the parameters determining the quality of an operator's reaction in work at a control desk is the coordination of the motor reaction.

We studied the coordination of the operator's movements in reaction to a binary sequence of signals of a definite probability structure. The motor components of the reaction consisted in throwing a tumbler switch to one of its extreme positions and then returning it to the initial point. Disturbances in the coordination of motion consisted in the operator's either failing to return the switch to its initial position or running past it. The design of the tumbler switch made it possible to determine the extent of such disturbances.

In the experiments with reaction to a sequence of signals of red and green light we found that the relative frequency of the uncoordinated responses increased with decreasing intersignal intervals.

Thus, when the signals were shown with a probability of 1/2 at 5-sec intervals, this factor was 0.031 but increased to 0.063 for an interval of 0.2 sec. We noted the dependence of this index on the latency period of the reaction and the time of its motor component. As these time parameters increased,

the relative frequency of uncoordinated responses decreased. A direct relationship was also established between the magnitude of this index and the relative frequency of errors.

The level of practical training of operators for work at control desks is correlated with the index of relative frequency of uncoordinated responses (the coefficient of correlation was 0.516).

As skill in work with the tumbler switch improved, the number of un- /128 coordinated responses decreased. In our studies, a relatively constant level of this index was reached after 3 - 5 training periods.

SPEED OF A SIMPLE SENSORIMOTOR REACTION TO NONSIMULTANEOUS AND SIMULTANEOUS ACTION OF STIMULI OF DIFFERENT MODALITIES

## A.S.Yegorov and B.N.Yakovets (Leningrad)

It is well known from the literature that the speed of a simple sensorimotor reaction depends particularily on the modality of the stimulus. Thus,
the reaction time is shortest on application of a tactual stimulus, followed in
increasing order by reactions to sound, to light, and to other stimuli. But
what will be the reaction time to simultaneous application of a tactual, visual,
and acoustic stimulus? Will this time correspond to the average reaction time
from any leading receptor, or will it be the shortest of these times? These
were questions that arose on an analysis of the literature.

To obtain an answer, the following experimental study was performed on 20 students of the P.F.Lesgaft GDOIFK, who were athletes in various fields and of various skills.

In the investigation, we used a reflexometric apparatus designed by Yu.N. Verkhalo\*, permitting separate or simultaneous application of a tactual stimulus (electromagnetic vibrations of a plate), an acoustic stimulus (sound generator) and a visual stimulus (the flash of an orange-colored lamp). The experiments were laid out as follows:

After 20 trials we ran a series of reactions to light, then to sound, and to the tactual stimulus, with 30 reactions each in the series. The intertrial intervals were 3 - 5 min. Then, a 10-minute break, after ten trials, was followed by a series of reactions to the simultaneous application of tactual, visual, and auditory stimuli.

The subject was instructed in all cases to remove the finger from a key as fast as possible, in response to the stimulus. In the case of simultaneous application of the stimuli, the subjects were permitted to choose the stimulus on which they would concentrate their attention.

<sup>\*</sup> A detailed description of this apparatus is given in "Teoriya i Prakt. Fiz-ikult".No.8 (1963).

## REACTION TIME UNDER NONSIMULTANEOUS AND SIMULTANEOUS APPLICATION OF STIMULI

	Reaction Time in Sigmas	
Stimulus	x	σ
Light Sound	230 200	45 58
Vibration of plate All three combined	200 180	75 50

These data are reliable, at a confidence level of 0.05. They indicate that the speed of reaction to a tactual stimulus does not differ substantially from the speed of reaction to sound. This may possibly be explained by the relative weakness of the tactual stimulus.

The longest reaction time shown on simultaneous presentation of all stimuli may be explained by the law of the strength of the effect of summation of stimuli.

DEPENDENCE OF THE ACCURACY OF REACTION TO A MOVING POINTER ON THE SHAPE OF THE DIAL AND THE RATE OF MOTION

### S.A.Pauzhayte (Leningrad)

The study of the reaction to moving objects is not only of theoretical importance in the investigation of visual perception of speed and direction, but is also of practical interest.

Our study of the reactions to a moving object were made on a model of a control desk equipped with four dials of different shape: circular, semicircular, horizontal rectangular, and vertical rectangular. All dials were 300 mm long. The pointers on the dials were actuated by an electric motor. An electromagnetic brake was used to start and stop the pointers. The pointer speed was varied:  $V_1 = 30$  mm/sec;  $V_2 = 60$  mm/sec, and  $V_3 = 75$  mm/sec. By depressing a key, the subject put the pointer in motion and by removing his finger from the key he left the pointer as close as possible to a specified scale division.

The results show that the most exact reactions to the moving pointer /130 were obtained on the circular dial and the least exact, on the vertical rectangular dial. The conditions for visual perception of the pointer movement on the circular, semicircular, and horizontal dials, which are more favorable than on the vertical dial, encourage high accuracy of the reaction. This is evidently connected with the nature of eye movements. A study of eye movements

(Yu.B.Gippenreyter and V.A.Urazayeva) showed that eye movements in the horizontal direction are smoother and more uniform than in the vertical direction. The number of accurate reactions with a circular dial was 1.5 - 2 times as great as with the other dials.

The average time error at a speed of 30 mm/sec is 50 msec for the circular dial, 66 msec for the semicircular, 65 msec for the horizontal and 79 msec for the vertical. At this speed, 60 - 70% of the time errors are in the range from 33 to 66 msec.

The number of delayed reactions at  $V_1$  is about 50% and the number of premature reactions, 20 - 30%. Most of the subjects tend toward delayed reactions.

With increasing pointer speed ( $V_2$  = 60 mm/sec) the time errors decrease. For a round dial their average value was 41 msec, for the semicircular, 56 msec, and for the horizontal, 62 msec. The number of accurate reactions was almost the same as for  $V_1$  = 30 mm/sec. A pointer speed of 60 mm/sec was the most convenient for most of the subjects. High-speed visual stimuli are more accurately perceived than low-speed stimuli, which is evidently due to the higher frequency of eye movements.

With increasing pointer speed the number of delayed reactions increases slightly, and the number of premature reactions decreases correspondingly.

At a pointer speed of 75 mm/sec, the number of accurate reactions decreases, and the time errors, on the average, increase slightly for some subjects and decrease for others. At a great increase in pointer speed to about 250 mm/sec, the time errors decrease for most of the subjects.

The pointer speed at which the subjects give the greatest number of accurate reactions and have the smallest time errors varies for different subjects.

In almost all subjects, the time errors decreased with increasing pointer speed: There is an adaptation of the visual analysor to high pointer speeds. Only in some subjects did we note a tendency for the time errors to increase with increasing pointer speed, but at a substantial increase in pointer speed the time errors decreased even in these subjects.

An accurate reaction can be obtained by advancing the definite instant of approach of the pointer to the required scale division, since a certain time /131 is required for the transmission of nervous excitation from the visual receptor to the effector. The exact magnitude of the advance depends on the perception of the speed of the pointer movement, connected with the estimate of space and time, and the speed of reaction of the subject.

An analysis of the dynamics of the individual reaction shows that the subjects are oriented to definite time intervals, and that they develop a "sense of time" but that also other modes of regulation come into play.

The accuracy of the reaction to a moving pointer when its path is gradually lengthened depends on the speed and direction of the movement of the visual stimulus.

### THE SYSTEMICITY OF THE RESPONSE REACTIONS IN A SITUATION OF CHOICE

# M.S.Yeritsyan and N.S.Kocharyan (Yerevan)

At the control desks for industrial processes, the operators must frequently react to systems of signals by consecutive depressing of buttons. In such cases, the success of the operator's work depends not only on the factor of reaction time but also on the character of the systemicity of both the buttons and the signals corresponding to them; inaccuracy of reaction to only a single one of the buttons is equivalent to inaccuracy of response to the system as a whole.

This fact may obviously be regarded as a manifestation of the role of the systemicity of the response reactions in a situation of choice.

To study the role of systemicity of the signals appearing on an information panel and of their corresponding buttons, the student subjects before and after the testing, were given the following task: On a vertical panel (beyond a ground glass) appeared six light signals of various colors (duration 0.4 sec, interval 0.8 sec); in response to these signals the corresponding buttons were to be selected out of eight of the same color on the horizontal panel, and they were to be pushed in time. If the correct button was pushed, a brief flash of the same color (0.3 sec) appeared in the lower portion of the corresponding signal.

In performing task No.1 (20 - 30 min before the test), signals II, III, and VI corresponded to buttons not only in color and time but also in spatial orientation. The button for signal I (on the right) was in the eighth position of the row, for signal IV in the fifth position, and for signal V in the /132 fourth position; buttons I and VII remained connected, but their corresponding signals did not flash.

Task No.2, given after the test (from 20 min to 1 hr), differed in that the signal for button II did not appear; instead, the signal for button I appeared in the eighth position of the vertical panel.

Thus, in the first task there were three signals, and in the second four, whose buttons were on diagonally intersecting lines.

Two experiments were made on each subject. The experiment was continued until the subject gave three cycles, i.e., 18 correct reactions in succession.

The appearance of the signals and the correct reactions of the subjects were recorded on tape.

In analyzing the data the following factors were taken into account:
a) total number of cycles of signals required for each subject to perform the task; b) number of reactions without result; c) correlation between a) and b) and marks received in the tests; d) type of button or combination of buttons pushed by the subjects to discover the systemicity.

The object of the last item was to establish which variants of response reactions were used by the subjects to attain the solution of the problem in a situation of choice.

The results of the analysis of the experimental data were as follows:

Problem No.1 (before the test) was solved by 115 subjects in the range of 7 to 53 repetitions of the cycles. The optimum was  $ll_4 - 17$  repetitions inclusive (M = 18.9).

Problem No.2 (after the test) was solved in the range from 5 to 30. The optimum was 11 - 16 repetitions inclusive (M = 13).

The overall results of the two problems were as follows: Of the 115 subjects:

- a) A total of 42, or 36% of the subjects, showed a decrease in the number of cycles after the test by a factor of 3 to 4;
  - b) A total of 25, or 21.6%, showed a decrease of 1/3;
- c) A total of 26, or about 22%, showed the same number of repetitions of cycles before and after the test:
- d) Finally, 22, or about 20%, showed an increase (by 2 7 repetitions) in the number of cycles after the test.

In solving problem No.1, i.e., before the test, 112 subjects had reactions without result (an average of 5.2 per subject). After the test (problem No.2) such reactions or misses were noted in 97 subjects (an average of 3.4 per subject).

A study of the unsuccessful reactions showed that some subjects produced them deliberately (as search movements). Most of the subjects solved the problem by the method of trial and error instead of by preliminary observation.

In 50.4% of the subjects [mostly from the subgroups (a) and (d) given above], the results of solving problem No.2 (after the tests) agree with the marks received by them in the tests [those given a high grade were in sub- /133 group (a), and those with the low grade in subgroup (d)].

To check these data we ran supplementary experiments on 100 students who had no tests during the experimental period. They required a much larger number of repetitions to solve the same problems (than the earlier group of 115 subjects).

In our opinion, this fact can be explained by the more active functional readiness (or adjustment) of the central nervous system in the subjects that had taken the test than in the subjects who were under the usual scholastic regime.

Under the conditions of solving our problems, 63 versions of response reactions were possible according to mathematical statistics, until the system of signals and their buttons had been found. One of these variants (unsuccessful reactions on the control system as a whole) has already been discussed.

The remaining 62 versions have the following frequency distribution in solving problem No.1 (before the test):

A total of 36 versions had a frequency from 0.001 to 0.005 inclusive (in units calculated by dividing the frequency of the particular variant by the total number, i.e., out of the 2040 response reactions obtained):

12 versions had a frequency from 0.006 to 0.010 inclusive; 4 versions, from 0.011 to 0.015 inclusive; 10 versions, from 0.023 to 0.039 inclusive.

In solving problem No.2 (after the test):

35 versions had a frequency from 0.001 to 0.005 inclusive;

8 versions, from 0.006 to 0.010 inclusive;

7 versions, from 0.011 to 0.015 inclusive:

6 versions, from 0.017 to 0.020 inclusive;

6 versions. from 0.021 to 0.038 inclusive.

It will be clear from these figures that most of the variants were very little used in the process of solving the two problems. Conversely, 12 versions, i.e., almost 20%, were frequently employed (it is sufficient to note that these 12 versions include 50% of all the reactions).

An analysis shows that the most frequently used versions of the response reactions were those in which the buttons are located along the edges of the horizontal row. The lowest frequency of response reactions was found in the versions whose buttons are located mainly at the center of the same row. We note again that the two center buttons (IV and V) in the two problems have the opposite position with respect to the signals.

Our data on the frequency distribution of these several versions confirm the well-known psychological fact of the difficulty in differentiating the central elements (especially in the visual field of perception) by comparison with the extreme elements. In this connection, the question arises whether it would not be advisable to locate the buttons of major importance in the central /134 zone of the system, as recommended by several specialists on engineering psychology, and close together.

ON THE VERBAL REPRODUCTION OF A CHAIN OF SUCCESSIVE LIGHT SIGNALS AND THEIR REFLECTION ON THE ELECTROENCEPHALOGRAPH

A.K.Astaf<sup>†</sup>yev (Leningrad)

Work at control desks and in automatized systems leads to a disuse of human motor functions.

M.I. Vinogradov emphasizes that "the disuse of motor functions will undoubtedly progress further in the future, going even as far as such functions being replaced by verbal control of the equipment, with a limited number of

commands and with semantic processing of the spoken signals".

This gives extreme importance to investigations on verbal reports in work with recording automatic plants.

The object of the present study was to elucidate the physiological mechanism of mastery of signals successively given to a program device of the type of a control desk, work on which consists in remembering the displayed signals and subsequently reproducing them verbally.

The programming equipment used in this study permitted a simulation of work involving prolonged and constant stress of visual attention.

The experimental setup comprised the following stages:

- a) giving the signals to the subject;
- b) recording his verbal interpretation.

The verbal interpretation was accompanied by recording of an electromyogram (EMG) from the circular muscle of the mouth (lead from the lower jaw) and of the electroencephalogram (EEG) from 10 leads.

The EMG permitted to judge, with sufficient accuracy, the difficulties of the subject, from the pauses in the verbal report, while the EEG yielded additional data on the intercentral and interhemispheric relations which appeared during the experiments.

The programs contained an equal number of red, yellow, and green signals displayed in various sequences.

The subjects memorized the yellow-colored signals most rapidly and the red signals least rapidly, although the red signals, according to the generally accepted view, exert the strongest influence on the visual analysor. This peculiarity can be explained by the second-signal-system significance of light stimuli in connection with their arrangement in the assigned program, /135 which primarily attracted the attention of the subjects. In the other programs, where green light appeared under analogous conditions, the smallest number of errors were made on precisely the yellow signal.

The following order of mastery of the signal complexes was characteristic:

- a) After the first display, the subjects correctly reproduced only the three first signals (first group), meaning that the dominant of attention was connected with the beginning of the complex.
- b) Further progress of learning did not proceed by successive increase of the correct responses but selectively: After the first group, the third or fourth group was correctly reproduced, followed only then by correct reproduction of the second. The second signal group was frequently passed over entirely. This may be explained by the mechanism of conjugate inhibition in the sphere of perception.

c) During the process of learning in the next stage, the subjects begin to master the groups that were at first omitted (second), but in this case they do not reproduce, or make mistakes in, groups previously mastered (first and third).

Consequently, on transfer of the dominant of attention to the signals not yet mastered, we observe the conjugate inhibition of the previously mastered signals.

- d) Further attempts by the subjects to reproduce the signal complex correctly lead to a position of conflict: The subjects suddenly "forget" the whole program at once, which can be understood as a development of ultraliminal inhibition of the type of "primary" fatigue described by M.I.Vinogradov. This is often preceded by the phenomenon of radiation of excitation, by expressed reproductions that are superfluous by comparison with the program, and by a large number of errors.
- e) During the training process, there is a stage in which, instead of the next group of signals, the subject reproduces the last group according to a "pattern". This is a manifestation of the mechanism of inertia of the dominant, stereotype.
  - f) Further attempts led to successful performance of the program.

An analysis of the EEG showed that during the period of mastery of the program the fast rhythm (20 - 80 cps) predominates in the leads from the anterior areas of the left hemisphere. At the instant of greatest difficulty the "focus" of the part of the activity may, in time, shift from one hemisphere to another and back again.

In a number of experiments the program was mastered in the presence of a focus of fast rhythms in the right hemisphere.

These facts indicate the existence of intercentral reorganization during the period of formation of the work of constellation of the nerve centers.

CONTRIBUTION TO THE QUESTION OF EVALUATION OF THE SPEED OF INFORMATION PROCESSING IN BINARY SERIAL REACTION

<u>/136</u>

# V.A.Bodrov, A.A.Genkin and G.M.Zarakovskiy (Leningrad)

With a uniquely determined reaction to signals of two kinds constituting a sequence, the frequency of errors and the reaction time are functions of the probability distribution of the signals (Bodrov, Genkin and Zarakovskiy, 1961 to 1963; Leont'yev and Krinchik, 1961 - 1963).

With respect to the frequency of errors this relation has been verified for various modalities and degrees of complexity of the signals. In the general form, if  $P_1$  is the probability of occurrence of a signal of one kind, and  $P_2$  =  $(1-P_1)$ , that of occurrence of the second kind, then the probability of

error for a signal  $P_1^{er} = C^{\sqrt{P_1}}$  and the probability of error for two signals  $P_2^{er} = C^{\sqrt{1-P}}$ , where C is a constant characterizing the experimental conditions.

These experiments were performed at relatively long intersignal intervals (5 - 10 sec). However, these formulas cannot be used to estimate the rate of information processing by a human subject, since they do not reflect the theoretically expected dependence of the probability of errors on the intervals.

In an experiment with light signals, we studied the correlation of errors and reaction time with the interval between the reaction to the preceding signal and the beginning of the next signal (D). The intervals used were 0.2, 1.0, and 5.0 sec.

We found that for the prescribed statistical structure of the signal sequence, the probability of error is

$$R_{i(D)}^{er} = P_i^{er} + \frac{K}{V\overline{D}} (i=1.2),$$

where Pi' is the probability of error in such an interval when Pi' depends only on the statistical structure of the sequence, and K is a constant characterizing the experimental conditions.

Thus, we get

$$P_1^{er} = C^{\sqrt{P_1}} + \frac{K}{\sqrt{D}} \text{ and } P_2^{er} = C^{\sqrt{1-P_1}} + \frac{K}{\sqrt{D}},$$

where D is less than 2-3 sec, and C and K are constants.

Within the intervals investigated, the time (T) was found to depend on D by the law

$$T = 0.16D + (0.44 \pm K)$$
,

where  $K = f(P_1)$ .

This law may, conjecturally, be explained by the increase in excita- /137 bility of the central nervous system when the tempo of reaction is increased.

A knowledge of these relations permits us to estimate the rate of information processing by a human being as a function of the binary statistical structure of the signal sequence and of the interval between the reaction and the next signal.

It is expedient to distinguish two forms of the rate of information processing in serial reaction:

The single-step rate:

$$S_0 = \frac{\overline{I}}{\overline{T}}$$
,

where  $\overline{I} = f(P^{er})$  is the mean quantity of information transferred per signal, and T is the mean reaction time per signal;

The serial rate:

$$\mathcal{S}_s = \frac{\overline{I}}{\overline{T} + D} \ .$$

ON THE TIME CHARACTERISTIC OF THE COMPONENTS OF THE PROCESS OF INFORMATION PROCESSING BY AN OPERATOR

V.A.Yegorov (Leningrad)

The process of information processing by a person is complex. In controlling a unit, the operator must identify a signal by determining its significance (perform a sensory selection) and choose an adequate motor reaction.

For the possible calculation of these elements, we performed two series of experiments on 16 subjects, using specially designed equipment simulating aircraft controls.

In the first series, the subjects were instructed to choose between two acoustic signals (sensory selection) to one of which they were to respond by a simple almost constant movement of the control stick (there was no motor selection).

In the second series, the acoustic signal was always constant (there was no sensory selection). To this signal, the subject responded by movements of varying complexity on the control levers (with one hand, with two hands, with one hand and one foot, with two hands and one foot, in various directions).

We found that, on sensory selection from two signals, the average time /138 for processing one bit of information, determined by subtracting the latency period of the simple reaction from the latency period of the reaction with the selection, was 0.145 sec.

The time required to execute the movements, which was determined by subtracting, from the time of the latency periods of the more complex movements, the time of the latency period of the less complex movements, was 0.035 sec.

The total time in sensory selection and in buildup of the movements was 0.180 sec, which is very close to the figure obtained previously by us, when the subjects were to effect simultaneously a sensory and a motor choice with complex movements (the average was 0.185 sec).

These data suggest that, in the complex process of information processing by an operator, it is possible to distinguish a sensory and a motor component, most of the time (about 80%) being spent on the sensory component.

ON THE APPLICATION OF THE METHODS OF INFORMATION THEORY TO THE STUDY OF THE MOTOR ACTIVITY OF AIRCRAFT PILOTS UNDER LABORATORY CONDITIONS

V.A. Yegorov (Leningrad)

In flying a modern aircraft, the pilot receives a large amount of information from various sources and must react to it by complex motor reactions designed to change the flight parameters.

The object of this study was to determine the ability of flight personnel to perform movements, appropriately gaged in amplitude and direction, on an apparatus simulating the controls of an aircraft. Displacement of the levers produced a synchronous deflection of the pointers of voltmeters mounted in the form of an instrument board. The signal stimulus used was an electric bulb, also placed on the instrument board. The movements were recorded on photographic paper by the aid of an oscillograph.

Interpretation of the records showed the length of the latency period of the motor reaction, the time of shifting the controls, and the accuracy (errors committed) of the amplitude and direction of the movements.

The task of the subjects was to move the pointers from one prescribed position to another by one lever, or by several levers simultaneously in various combinations, under visual supervision and without it (with covered instruments).

The resultant data were worked up by calculating the information processed (by the Brillouin formula) and by computing the handling capacity of the subjects in this activity.

The experiments were made on two groups of subjects. The main group consisted of 60 aviators in various types of aviation; the control group had 31 persons unconnected with flying.

We found that the flight personnel had a higher handling capacity than the control group, especially in performing complex movements with two and three levers. We also found a correlation between the level of flight training and the handling capacity. In the absence of visual supervision, the degree of error increased and, in spite of a somewhat greater speed in shifting the levers, the handling capacity decreased within the range of one bit.

In complex movements, when the subject must simultaneously follow the readings of two or three instruments, the capabilities of the visual receptor are limited, and the control of the accuracy of the movements is accomplished with a greater participation of proprioceptive sensitivity. This is expressed

in a decrease in the difference between the handling capacity with and without visual control in executing complex movements, by comparison with the simple movements, in which only a single lever is shifted and the operator observes only a single instrument.

### CONTRIBUTION TO THE QUESTION OF THE REACTIONS OF CHOICE IN HUMAN SUBJECTS

V.T.Prodan (Leningrad)

The information-theory approach to the analysis of human activity has an extremely short history. This approach is adequate for studying signal sequences and their processing by the human central nervous system. The most convenient method of making the information-theory approach possible is the study of choice reactions.

In most experiments devoted to the choice reactions, the subjects were given a small number of alternatives from which to choose, and the tests were commenced after a certain preliminary training. This is explained by the problem posed by the experimenters. They determined the relation between the time of reaction to a signal and its information content. During the course of these studies it was found that a more detailed analysis of the development of the choice reaction itself was necessary, since the reaction time depends on a large number of conditions. When the number of alternatives is small, the /140 performance proceeds so rapidly that it is difficult to analyze.

The present investigation touches on the little-studied question of the formation of the choice reaction during the training process itself, and also of its features when the choice is to be made from a large number of alternatives.

The subject worked at an especially designed model of a control desk. Its keyboard section had 30 keys, arranged in three rows of 10 each. On the moving strip chart of an ink-writing Ediswan oscillograph, the latency periods of the choice reactions were recorded. The signals given were well known to the subjects, since they were the letters of the Russian alphabet. After the experimenter pronounced a letter, the subject was required, without error and as rapidly as possible, to press one of the 30 keys corresponding to that letter. Thus the "alphabet" of the signals applied was well known to the subjects. individual letters were dictated from a text starting from the end so that the subjects could not catch its meaning which, of course, would have had a strong effect on the length of the latency periods. During each experiment not less than 2000 letter signals were dictated to the subject. This number was used since, in this case, the statistical regularity of the varying frequency of the letters in texts is already established. Knowing the probability of occurrence of each letter in the text, we thus also knew the individual information contained in each signal. In all, 15 experiments were performed on two subjects.

During the test, the length of the latency period of reaction shortened by a factor of 2 to 3 for each letter. Thus the latency period per signal

varied strongly, although its information content remained the same.

Two stages could be noted during the course of the test. During the first stage. the latency period of reaction to the letter signals, corresponding to the extreme keys of each of the three rows, sharply decreased and were approximately equal for all signals, regardless of their information content. The length of the latent reaction periods to signals corresponding to keys in the center of the rows remain considerably higher than for the keys at the extreme ends. Here, likewise, we were unable to find a relationship between the latency period of reaction to a signal and its information content. Thus, the subjects divided the entire alphabet into three equal parts corresponding to the position of the keys in the motor region. During the second stage of the test (beginning with the sixth to seventh experiment) the length of the latency periods to signals corresponding to the center keys began to approach the reaction time for the end keys. By the thirteenth experiment there was already a distinct relationship between the time of reaction to a signal and its information content for the central elements in each row. As for the reaction times for the end keys, it remained, as before, independent of the information content of the signal.

Thus, in the first stage of the test, the subjects made use of the widely known principle of division of a whole into parts, considerably facilitating search. At this stage, the search was transformed from local to nonlocal.

As for the content of the signals, it was perceived by the subject already in the second stage of the test and, obviously, the later, the longer the "alphabet".

Here we must also note that the rate of presenting the signal has a strong influence on the rate of its processing. In our experiments, with an interval of 0.5 - 1 sec between presentation of the next signal after response to the preceding one, the choice reaction time was hardly more than half that for the 4 - 8 sec interval. The position of the pressed key is retained in the memory for a certain time, thus affecting the latency period of the next choice reaction. Consequently, if pressing the key that corresponds to the letter "O" is followed by the letter signal "P" within 0.5 - 1 sec, then its latency period was only half as long as usual; but if the interval was increased, this effect disappeared. This is obviously due to the properties of the trace processes in the central nervous system.

EFFECT OF CONDITIONAL PROBABILITIES OF A SEQUENCE OF SIGNALS ON THE TWO-CHOICE UNIQUELY DETERMINED REACTION

# I.N.Krylov and K.A.Smirnov (Leningrad)

In works devoted to the investigation of the parameters of uniquely determined reactions as they depend on the statistical structure of the signal sequences, the relations connected with the unconditional probability of occurrence of stimuli was investigated (Bodrov, Genkin and Zarakovskiy; Leont'yev and Krinchik). The object of our experiments was to study the effect on the

reaction time and error frequency of the conditional probabilities (probabilities of the second order) of the succession of two signals.

The signals used were red (R) and green (G) light. In a series of experiments with "bilateral" reaction on appearance of each type of signal, the subject was to turn a key to the corresponding side (following instructions). In series with "unilateral" reaction, the signal "G" appeared as inhibitory.

We used four programs with the following statistical structure:

$$\begin{split} 1 - P_{\text{GG}} &= P_{\text{RR}} = P_{\text{RG}} = P_{\text{GR}} = \frac{1}{2} \; ; \quad || - P_{\text{GG}} = P_{\text{RR}} = \frac{1}{6} \; ; \\ P_{\text{RG}} &= P_{\text{GR}} = \frac{5}{6} \; ; \quad ||| - P_{\text{GG}} = P_{\text{RR}} = \frac{5}{6} \; , \quad P_{\text{RG}} = P_{\text{GR}} = \frac{1}{6} \; , \\ |||| 1 - P_{\text{GG}} = P_{\text{RR}} = \frac{2}{3} \; , \quad P_{\text{RG}} = P_{\text{GR}} = \frac{1}{3} \; . \end{split}$$

The unconditional probabilities were  $\frac{1}{2}$ .

Each of the five subjects was given 720 signals for each program and form of reaction. In one experiment, 240 signals were given.

We found that in the case of "bilateral" reaction, the error frequency for a given signal increased with decreasing conditional probability of the succession of a given signal after the preceding signal, in accordance with a definite law.

The reaction time likewise increases, but at a slower rate.

The mean losses of information stayed at a constant level (about 0.25 bit per side).

In the case of "unilateral reaction", all the errors fell on the inhibitory signal. With decreasing conditional probability of this signal, the error frequency increased. The reaction time to the positive signal increased with a decrease in its conditional probability.

The error frequency to an inhibitory signal following a positive signal was found to be higher than when it followed another inhibitory signal. This fact permits certain considerations on the physiological mechanisms of the regularities observed.

# CONTRIBUTION TO THE COMPARATIVE ANALYSIS OF THE PROCESS OF SOLVING PROBLEMS ON ELECTRONIC COMPUTERS AND HUMAN INTELLECTUAL ACTIVITY

### O.K.Tikhomirov (Moscow)

The general problematics of engineering psychology include the special problem of the relation between the functions of man and computer, and in particular of the intellectual functions. In this specialized field, the man/machine problem is concretized in the study of the correlation between the program according to which problems are solved on a computer and the "program" according to which the process of solving problems by a human subject is constructed.

The study of the "program" used in constructing the process of solving problems by human subjects can be of dual significance: a) It can serve as a source of the information required for further improvement of the machine programs; and b) it can encourage the optimum division of functions between man and machine.

Many of the problems that arise in an operator's work have the following features: They are "nonarithmetic", i.e., the solution consists in the selection of one of a set of possible methods of action; among these methods there is no strict division into correct and incorrect but a gradual gradation from the best to the worst solution; the problem is to find a method that is both good enough and simple enough; the conditions of the activity are of a "conflict" character (in the sense used in the mathematical theory of games). All these characteristics are possessed by those problems in the selection of good moves, whose sequence of solution constitutes the game of chess. For this reason, it was found useful to select the game of chess as a model for studying the questions formulated, which may prove useful in the solution of more important problems.

One of the important methods of comparative analysis of the functions of man and computer are games between a man and a machine, and in particular the game of chess, in which there takes place a so-called practical comparison of the abilities of man with those of the computer.

The author's application of this method of investigation has shown that one of the most important characteristics of the solution of game problems by man consists in the highest selectivity of the objective utilization of the given conditions of a problem. It is exactly in this stage that the "advantage" of the human subject is disclosed, and an analysis of this stage is mandatory for further improvement of the programming of problem solutions on computers.

#### DEVELOPMENT OF THE CONCEPT OF MACHINE THINKING

# A.M.Parachëv (Leningrad)

The engineering development of "thinking" robots is made difficult by the lack, in contemporary psychology, of any unitary and distinct conception of what constitutes human thought. Engineers are therefore independently compelled to formulate the concepts of thinking and to depart from them only if they are unsuitable for the construction of automatic machines, or to limit the field of application of some concept and work out a new one. Up to now, several working concepts of thinking may be distinguished.

The <u>algorithmic</u> viewpoint consists in the assertion that the process of thought is amenable to description by the aid of certain algorithms. The improvement of the process will consist in a random recombination of some set of operations and the selection of those that satisfy a definite preassigned criterion of quality. This direction of research is called "artificial intelligence".

The <u>heuristic</u> approach to thought starts from the postulate that beneath the ordinary logical operations lies a system of heuristics, i.e., rules for finding a solution, which lead to success in most cases but not always. The working hypothesis adopted is that there exists a finite collection of heuristics describing any process of solution of a problem, and the object of determining these heuristics is posed. The studies are performed both on digital computers and in the psychological laboratory. For work on digital computers, a special system of coding ("information-processing language") has been developed. This line of research is called "heuristic programming".

The above concepts relate to the operational aspect of intellectual activity, and ignore the sapid aspect of thinking. Recently, a tendency has been noted to go beyond this limitation and to include in the analysis of intelligence also so-called "internal models of the external world". Two stages of development of this concept can be distinguished.

The internal model of the external world is the foundation for the formation of both algorithms and heuristics. On the basis of the model, the construction of the plan of activity and its control are accomplished. Here there arises the problem of integrating the information on the laws of the external world into the structure (algorithm, heuristic, plan) of activity in it. This problem has not yet found an engineering solution.

Finally there arises a problem of the analysis of complex information systems capable of independently developing internal models of the external world, of planning its activity on the basis of this model, of transforming the model on the basis of experience, and again planning its activity. This evidently is a rather remote prospect for the development of the concept of machine thinking, and we are only approaching it.

The concepts of machine thinking here considered are stages in the successive approximation to the understanding of nature by human intelligence and,

at the same time, stages of ever-increasing improvement of automatic control systems.

#### ON THE SIMULATION OF A CLASS OF INTELLECTUAL OPERATIONS

### G.M.Khovanov (Moscow)

Computer technology today is used for the solution of problems from the most varied fields of knowledge. However, the machine is far from being able to make all of the decisions that can be made by man, since by no means, all knowledge can be formalized and expressed in equations. In many fields such as, for example, in forward economic planning or chemical engineering, there exist only simplified mathematical models of the processes, which are able to describe and predict the processes considerably less efficiently than an experienced specialist who relies on nonformalized past experience and on "intuition".

Nevertheless, the lack of an exact mathematical theory of a given process does not exclude the possibility of the use of a computer, which is obvious from the example of self-teaching programs for the recognition of forms which, in the absence of a prescribed mathematical theory, indicate which of the outcomes of a random event is the most probable.

The most general problem is that of the quantitative estimate of the probabilities of outcomes of a random event, on the basis of wide and varied past experience, when the use of statistical methods cannot cover all the data on the structure of this experience. Man is unable to solve such a problem /146 as an isolated case (i.e., he cannot state the numerical values of these probabilities), but experienced specialists readily solve problems of this type as soon as they become concrete (i.e., the specialist takes a decision that is close to optimum).

Conversations with specialists have shown that experience is evidently manifested in the correct organization of past experience, in knowing how to choose correctly situations for drawing analogies to a given situation. The attempt to simulate such a utilization of past experience could be significant both for questions of the use of machines in science, industry, and planning and for the study of the cognitive activity of man.

Let a random event be observed under different conditions, differing by two (or more) qualitative attributes. Required: to estimate the probability  $P_{lofok}$  of the  $k^{th}$  outcome of this random event, if the first attribute has the value i=i and the second attribute the value j=j. To evaluate  $P_{lojok}$ , let us make use of the value of the relative frequencies  $\nu_{lojok}$ , of this same outcome at other values of the first attribute, but at the same value of the second. If we imagine that the distributions of  $\nu_{i,j,k}$  over K are located in the cells of a matrix for which i denotes the number of the row and j the number of the column, then we shall be able to say that the distribution  $P_{lojok}$  is set up according to the distributions of  $\nu_{lojok}$ , i.e., from different cells of the same column, taking account of certain coefficients of similarity wi i between

the given row i and the rows of i.

$$P_{iojok} = \frac{\sum_{i} w_{i_0} i_{v_{ijok}} + \frac{1}{n}}{\sum_{i} w_{i_0} i_{i} + 1} \quad (K = 1, 2, ..., n)$$

It is an operation of higher rank to find the coefficients of similarity between the rows, with respect to the remaining columns, on the basis of the relative frequency distribution  $Wi_1 i_2 = \sum_{j\neq i_0} \{(vi_1jk), (vi_2jk)\}$ . If the pre-

ceding operation is analogous to the evaluation of probability by a human subject, then this operation is analogous to the formation of "an association".

It is an operation of still higher rank to find the form of a function f, so selected as to minimize the sum of the expressions  $\sum_{k} {}^{\gamma} ijk \frac{\log \frac{\sqrt{ijk}}{Pijk}}{Pijk} \quad \text{for all}$ 

cells of the matrix, i.e., to minimize the mean quantity of information for the entire matrix which can be derived by substituting the predicted probabilities for the empirical frequencies. To find the function f is the analog of the formation (in phylogenesis) of the psychophysiological mechanisms of thought together with the formation (in ontogenesis) of the general methods, the "style" of thinking.

The operation of selecting the attributes from which the matrix is /147 constructed must also depend on the above criteria of information theory and serve as an analog for the structuring of past experience by members of the human society. In many practical control problems (for instance in processes of chemical engineering) it is by no means always necessary to turn this problem over to a computer, although in some cases (for example, an automatic machine landed on the surface of an unexplored planet) such a necessity is obvious.

ON THE UTILIZATION OF CHESS AS A MODEL OF OPERATIVE THINKING

V.N.Pushkin (Moscow)

The game of chess was created from the very beginning as a model of the activity of military leaders, which is a typical variety of operative thinking. The fundamental propositions of the psychology of practical thinking as a specific variety of human intellect were actually formulated on the basis of a psychological analysis of a General (Teplov). There have been few psychological studies of the game of chess itself (Binet, Cleveland, Severniy, Blumenfeld, Rudik); and occasional psychological questions have been raised in the specialized literature of chess as well (Lasker). These studies give only a macro-analysis of the game of chess. The immense possibilities of chess as an experimental model for investigating such major problems of the psychology of operative thinking as the mechanisms of problem solution, the formation of thought processes, of operative talent and the like, have long remained unutilized.

Studies on the psychology of the game of chess have recently become quite important in connection with the development of cybernetic machines. Chess has become a touchstone for elucidating the possibilities of automation of human intellectual activity. In spite of occasional successes in heuristic programming (Reitman, Samuel, Newell, and others), the possibilities of chess machines are still very small, and in this connection the comparison of man and machine on the chess board acquires fundamental significance (Botvinnik).

The process of solution of chess problems was selected as the object of the present study. The experimental problem was a study in which the subject was instructed to play for a draw, taking the white side. During the solution of this problem, the chess player would first have to pose and formulate /148 this problem for himself, and only afterward solve it. The experimental problem situation can be qualified as open. The leading role in its solution is played by visual analysis of the elements, their properties, and their mutual positions. The significance of the visual receptor for the solution of chess problems permitted us to use a motion picture of the eyes in order to obtain an objective record of the process of solution, followed by a frame-by-frame work-up of the material. (This method of registration for analyzing the processes of operative thinking was first used by D.N.Zavalishina.) The results of photography of the eyes in a survey of the experimental position agreed with the report of the subjects on the versions of the solution.

The results showed great intensity of work of the eyes during the solution of the chess problem. The mean fixation time of the eye on the various points is 0.24 sec. All the points of fixation of the eye may be divided into two groups. The first group includes stopping of the eye on those squares of the board occupied by chess pieces; the second group, fixation on the empty squares. There are grounds for believing that the second group of fixations is connected with an imaginary move of a piece onto an empty square, i.e., with the future move. The fixations of the first group may have an entirely different functional significance; the drawing of the eye on a piece might, conjecturally, mean: recognition of a piece, repeated examination of a piece with the object of extraction from it information that is still lacking, a glance at a piece in order to relate it to another piece.

The frequent repetitive returns to a piece already examined might mean that the oculomotor apparatus is connected with the "stamping-in" system of the brain: The eyes return to an element of the problem situation until information sufficient to solve the problem has been extracted.

We established the following phases of solution of the problem, characterized by the specific features of the path taken by the eyes: reading the situation, elucidating the problem, correlating the properties of the elements from the viewpoint of the problem, establishing a version of the solution, and its verification.

In studies, which likewise recorded the movements of the receptor organ (V.P.Zinchenko, B.F.Lomov) the significance of orientation in the process of perception was shown. In connection with the fact that, in our experiments, we recorded movements of the eyes that were close to orienting movements, it is necessary to determine the role of orientation in the solution of problems of

the chess type. Based on an initial analysis of the material, it can be postulated that orientation in the strict sense of the term begins with the reading of the situation and ends with the elucidation and formulation of the problem. Orientation is the search for the problem. After the problem has been formulated, orientation is replaced by purposeful analytic-synthetic activity. On further solution, it is possible to have a version in which it is found that the problem had been incorrectly posed and that the conditions should be /149 revised; in this case the orienting activity is again developed in full measure.

Our study has shown that the real process of solving the problems does not correspond to the concept of "sorting out of variants", which is based on the behavioristic theory of "trial and error" and which itself forms the basis for the programming of many chess-playing machines. An analysis of the solution of chess problems by a human subject may yield material for the construction of heuristic chess programs or for pinpointing the question of the boundaries of automation of the human intellect.

ANALYSIS OF THE PROCESS OF SOLVING SPATIAL-COMBINATORIAL PROBLEMS OF DISCRETE CHARACTER BY THE AID OF MOTION PICTURES OF EYE MOVEMENTS

# D.N.Zavalishina (Moscow)

In recent years there has been a trend in cybernetics (Newell, Shaw, Simon, Reitman) toward development of the problem of "heuristic programming", which attaches great importance to the study of the real process of human problemsolving behavior, as the basis for creating programs for cybernetic machines in solving complex problems. At the same time, the study of the real process of solution by man of certain types of problems is not only theoretically important but also constitutes a practical problem in connection with the automation of those forms of dispatcher and operator work whose major component consists of intellectual activity.

However, investigations on the process of solving problems encounter great methodological difficulties, in view of the fact that many elements of the intellectual process directed toward solution of a problem, usually elude the conscious inspection of man. In order to objectivize the process of solution, especially of the above subconscious elements, the method of motion pictures of eye movements (V.P.Zinchenko) in solving problems was employed.

As the object of study we used the process of solution of a problem which is a variant of the mathematical "15-game". This problem is a model of the activity of representative dispatcher work. It requires the player to pass, by the aid of "simple rook moves" from a prescribed situation to the normal situa-

tion  $\frac{123}{l.5}$ , leaving squares "d" free in both the final and initial moves. In

contrast to the earlier work by this technique, the transformation of the <a href="//l50">/150</a>
prescribed situation into the end situation was accomplished in the present ex-

periment on the basis of a visual analysis of the situation without actually moving the pieces. The problem was considered solved if the subject was able to name a set of moves leading to its solution. The problem discussed here belongs to the large class of problems of discrete character (to which chess also belongs). These problems are characterized by the fact that the opposing elements are given as objects separate and distinct from each other and that the solver discovers their properties and the relations essential for the solution of the problem in the course of the solution.

The experiment involves five situations in all. From the point of view of the demands made by various situations on the intellectual activity of man, the experiment was divided into three series. The problems presented in each series differed in the character of connection between their component elements. The first series included problems whose elements had a cyclic structure, i.e., were regularly disposed relative to each other from the point of view of the

demands of the end situation (situations  $\frac{412}{53}$  and  $\frac{541}{32}$ ). The solution of such

problems consists in a cyclic permutation of all its elements. For the solution of problems of the second series it was necessary at first to combine the separate elements or groups, i.e., to construct the system (for example, to

solve the problem  $\frac{124}{53}$  the piece 3 had to be combined with the group 12, while to solve the problem  $\frac{315}{24}$  the substructures  $\frac{31}{2}$  and  $\frac{5}{4}$  had to be developed

relative to each other). The solution of a problem of the third series for construction of a system requires the preliminary dissolution of the existing mutual position of the elements.

An analysis of the resultant data shows that the movement of the eyes is of different character in solving problems of different types. This indicates that we have here what might be called an objectivized process of intellectual activity. The process of perception in this case plays an ancillary role. A sketch of the eye movement and its time parameters permitted us to give a definite qualitative characterization of the process of solution. Thus, solution of problems of the first series was rapid and practically coincided with the reading of the situation. The solution of the problems of the second series was considerably slower. Thus, the mean number of fixations per solution of a problem in the first series was 20.8, but in the second it was 39. In addition, if in solving the problems of the first series, the pieces are arranged by the subject successively and without any particular preference, there will be a repeated positioning of the several groups of elements in the second series. As shown by the data, the problem with the greatest complexity for all subjects

was that of the third series  $\frac{451}{23}$ . The solution of this problem demanded /151

intense intellectual activity of the subjects. This activity was considerably more complex in structure than that in solving problems of the first two series. The mean number of fixations for the solution of a problem of the third series was 123. In addition the stepwise character of solution was rather distinctly

manifested. The following stages can be distinguished: initial analysis of the situation, identification of the subproblems (usually the pair 45 which had to be broken up), formation of a plan of solution and its implementation.

The data obtained indicate the potentialities of the method of motion-picture photography of eye movements for the study of the problem-solving behavior for problems of this class.

#### UNDERSTANDING OF A READILY VISUALIZED SITUATION

I.M.Geodakyan (Yerevan)

Understanding or comprehension is an essential component of human activity. It embraces psychic states of varying complexity, beginning with intelligent distinctly conscious perception and ranging to complex intellectual operations. The nature of human understanding defines the intellectual process, the "share" of thought at various levels of cognition. For this reason, when we speak of understanding, we should envisage an entire hierarchy of levels of thought, including the solution of problems which are both either purely verbal or have a visualized character. In the latter case, understanding is manifested as orientation in the situation, as adequate reaction to a system of simultaneous or consecutive stimuli.

The question arises: What is the "technique" of understanding, its features on the various levels of the intellectual process, which give it its greater or lesser complexity?

Our study was directed toward an interpretation of the psychological mechanism of simple understanding in a visualized situation. The experiment was the gradual guessing of the properties of an artificial stimulus. This consists of several sets of cards divided by rulings into individual cells. Each cell had two properties, color and number. The latter either belong to a certain rigid system or are determined by free (random) choice. In each system we used two or four colors and 16 figures. The subject was shown the first card, in which only the first cell had these properties. His task was to guess the properties of the second cell. After his answer he was shown the second card. Then the same procedure was repeated with the third card, etc. In other words, after each answer the subject was shown the corresponding part of the coded system. With each step the information obtained by the subject was increased and refined. Finally, at some point, error-free answers began to appear, i.e., the subject acquired cognizance of the system governing the position of the various properties or, on the other hand, he understood that a certain one of these characteristics did not fit into any system, i.e., had been taken on the basis of a random selection.

The experiments yielded the following findings:

1. On the level of understanding investigated here, all subjects showed uniformity in their problem-solving behavior; no individual differences were

- noted. This uniformity consisted in finding the most rational and economical solution process, dictated by the exhibited system.
- 2. Most of the subjects executed the same number of steps in finding the properties combined into a certain system.
- 3. Greater effort was required to understand the random character of one of the attributes; the deviations from the mean values also were greater. The search for a solution was Quite difficult in this case.
- 4. The experimental data permit several ways for this systematization. All subjects, however, grouped the attributes in the same way. The grouping was determined by the interrelations of the properties of the cells, by their number, and mutual position. Thus, in the system of sequences of four colors, these are not apprehended in time but only in space. On the other hand, the apprehension of two colors with a stable spatial position (in checkerboard form) does rely on a system of time sequences.
- 5. After several correct answers, errors sometimes occurred. In such cases the subjects shifted to a different mode of guessing; as it were, they put into operation a system of past experience that was more suitable for the given situation. If, on the visual level alone, it was impossible to fully grasp the operative system, the subjects began to utilize simple concepts (for example, even and odd numbers, etc.) which served as keys to the situation.
- 6. The utilization of certain concepts in systematizing the properties implies a more perfect form of intellectual activity, and is characteristic of the more sophisticated and more intellectual attitude of individuals.
- 7. During the process of apprehending a visual situation, definite systems, formed as a result of their experience in life, become actualized in the subjects. On relatively low levels of understanding, these are the same in all subjects and are conditioned by the character of the stimulus. It is these systems that we consider to be the mechanisms of understanding.

Thus, under the conditions of our experiments, there was for the most /153 part simple understanding, limited by the frame of the visual situation. In apprehending the properties of a signal, special mechanisms ensuring comprehension of the entire system were actualized. They were realized by ordering the properties in temporal or spatial sequence. In spatial orientation, moreover, the base was the arrangement of the same colors (in our experiments the diagonal direction dominated the vertical and horizontal directions). In the case of a causal connection between the colors and figures, the relations between the colors were apprehended earlier. All the answers of the subjects indicate a strong tendency to start from the already known connective properties of the signal in guessing those still unknown. Properties located a certain distance apart were not combined on a purely visualized plane.

In case of necessity, where it is impossible to apprehend a situation as a whole by the aid of visual, temporal, or spatial systems, the subjects have recourse to ideation. This is already a transition to a more complex level of understanding. The ideation serves for the correction of answers and elimina-

tion of errors.

#### FEATURES OF INVESTIGATIONS OF THOUGHT IN ENGINEERING PSYCHOLOGY

### A.M.Matyushkin (Moscow)

Questions of the psychology of thinking have not yet assumed their right-ful place in studies on engineering psychology. This has been due not so much to a lack of need for research of this kind as to the fact that the thought processes have not been worked out and are rather complex. There are also a number of specific causes responsible for the limited extent to which the known psychological laws of thought have been used in solving problems of engineering psychology.

- 1. The traditional psychological studies of thinking have in most cases been concerned with the thinking of a human subject as manifested in his everyday behavior, when confronted by certain practical or theoretical problems. The laws discovered in experimental research explain numerous facts of human behavior and are also used by many branches of science related to psychology (pedagogy, physiology, etc.) and the applied fields of knowledge. In all these cases the data of psychological investigations could be directly utilized, without any complex interpretation. In research in engineering psychology, however, in considering the various aspects of the man/machine problem, psychology was primarily confronted with several unsolved problems of perception and. secondly, with questions of the accuracy of the sensorimotor act performed by an operator. These two main fields of research were directly determined by the difficulties encountered by designers of complex control systems. It appeared here that all the complex functions that must be performed by a human subject under ordinary conditions (first of all, the necessity of "thinking") could be simulated by the aid of a more or less complex electronic computer. operator became an "element" in a system of receiving and transmitting information.
- 2. Under these conditions, the role and position of psychologists was naturally limited to the study of this rather narrow "element". Even with such a limited field of study and of psychology, however, the designers soon became convinced that optimum operation of a complex control system required the solution of a considerable number of problems outside the limits of studies of perception and sensorimotor functions. This led to the problems of training and selection of operators, the problems of "information coding", and even of "operative" thinking or reasoning.

The primary difficulty produced by the limited possibilities for the utilization of the psychological laws of thought were the considerable specificity of complex control systems. This peculiarity can be characterized by two principal features:

a) The main function of the system is performed only by the system as a whole. The individual operators in a complex system perform only individual elements of the common problems that the system is designed to solve.

b) The specificity of the operator's work in a complex control system consists in the fact that he must take decisions with respect to real objects on the basis of a complex system of signal images, which resolve the controlled object into its individual properties, relationships, and functions.

Thus, psychology was compelled from the very beginning to investigate only that partial activity of the operator which in most cases was limited to problems of perception and sensorimotor action. Even in cases where the real demands of system design expanded these narrow limits, when a whole succession of new problems arose, the traditional approach to the operator's activity still remained dominant.

It must be noted that, in very many cases, the functions of the operator actually comprise only perception and the performance of sensorimotor actions. But even in these cases, in contrast to a machine, the operator does perform these acts deliberately. The human subject is aware of the fact that the displays on the screen of the indicator represent certain real objects possessing certain properties. Thus, thinking actually is a process that is necessarily included in the process of perception. The human operator performs all those elements of activity which were not provided for by the designer, and searches for all the information that he requires for solution of the problems facing him.

Thinking of a complex control system as a whole, it becomes obvious that in most systems their function reduces primarily to the solution of a considerable number of intellectual problems. The entire automated part of the system serves only as a means for facilitating the solution of these problems by the human operator. Further than that, the most completely and most adequately automated functions and modes of human thinking are those that in essence are skills, i.e., the automated components of a complex human activity. This means that, without the faintest doubt, it is possible to have the computer take over the entire system of computing operations and certain methods of solving many complex problems. In a number of cases, these methods permit only a partial solution of complex problems (or solution under strictly prescribed conditions). making them, as before, merely a means to facilitate man's search for the correct solution for the problems involved. In many cases, when the computer's work is not sufficiently reliable, the operator himself must check and evaluate the correctness of the solutions found by the machine. All these facts show that in considering a complex control system the activity of the human element in the system can never be reduced to merely perception and sensorimotor action. The primary function and the ultimate result of the work of the system is to make decisions about the controlled objects, and this fundamental problem, as before, must be solved by the human link in the system. To find the optimum conditions that will facilitate the taking of rapid and accurate decisions by the human subject is a highly important problem of engineering psychology, but one which still has been little investigated. This problem can be solved only on the basis of an analysis of the combined activity performed by man in the various functional elements of the system.

#### CONTRIBUTION TO THE PROBLEM OF OPERATIVE MEMORY

# P.I.Zinchenko and G.V.Repkina (Kharkov)

The important laws discovered during the last few years in research on the dependence of the mechanisms of memory and the conditions of its productivity on the content and structure of the activity (P.I.Zinchenko, A.A.Smirnov and others) as well as the increasingly deep penetration of psychology into /156 practice (pedagogic activity, activity of the operator of automatic systems, etc.) have regularly led to the problem as to the role of memory in specific forms of activity and as to the relation of its results to various characteristics of the memory processes included in this activity and operatively serving it. This has been the origin of the problem of operative memory.

We are now investigating this problem, for which we have developed an experimental methodology and performed preliminary experiments.

Since operative memory has not been thoroughly investigated, data of the study of direct memory are often used for its characterization. Operative memory and direct memory do resemble each other in their brevity, but in structure (objects, aims, problems, methods) they are different forms of mnemic activity and have their own laws and peculiarities. This is also confirmed by the results of preliminary experiments. An identification of operative and direct memory is therefore impermissible despite the fact that an intimate interrelation exists between them.

The concept of operative memory (OM) embraces the processes of recent memory included in some specific activity, serving its requirements and constituting a condition of its success. The principal characteristics of OM are volume, lability, accuracy, and noise resistance. The operative units of memory (OUM) are the factors that are dominant in the characterization of the functioning of the OM and of its capacity.

These characteristics of the OM are derived from the content and features of the problem under the conditions of which it functions. Thus, our experiments have shown that various formulations of the problem in work with the same material, performed by several subjects, leads to a variation of the volume of OM over a wide range (from 3 - 4 digits to 12 digits in work with digits); the accuracy of solution fluctuates considerably (from 2 to 44% of erroneous answers); noise has a different effect (in some problems, this effect is slight, while in others it is responsible for as much as 50% of all the errors); the lability of the OM also varies substantially and is indirectly reflected both in the speed of problem-solving and in the character of the errors.

In studying the effectiveness of various methods of coding, we also found that a characterization of codes, even those of equally high value for perception, can be given only if the specific problems to be solved by the operator are taken into account. In solving problems involving the identification of objects, all codes were found to be practically equal in effectiveness. The performance of tasks requiring the participation of the OM sharply disturbed its

equilibrium; this disturbance was more pronounced, the greater the load on the OM. Even within the limits of a single method of coding, the results showed significant fluctuation, depending on the character of the problem.

The characteristics of the OM are closely interrelated. Their qualitative features depend substantially on the OUM, which means that the results of an activity are to a large extent determined by the character of the OUM used.

Thus, the codes for which the subjects have devised methods of processing developed by formation of various OUM, are the most effective; in using such codes, even an increase in the load on the OM has less effect on the results of the activity. In other experiments we found that, in performing the same tasks on a given material, the use of larger units leads to a sharp cut in the time of problem-solving, at equal or sometimes even at greater accuracy.

Experiments on the formation of OUM on school material confirmed the decisive significance of the quality of OUM and of the degree of their formation and automation for the overall results of the activity.

The major problem in the study of operative memory is the discovery of the laws of formation of its operative units, directly connected with the possibility of control by the OM. At the same time, the study of the entire complex of its characteristics and of their interrelations in various activities is of extreme importance.

### MEMORY CAPACITY, QUANTITY OF INFORMATION, AND NUMBER OF SYMBOLS

## P.I.Zinchenko and P.B.Nevel'skiy (Kharkov)

The authors made a comparative study of the influence exerted on the memory capacity by the quantity of information contained in the symbols to be remembered and by the number of such symbols. With this objective in mind, three experiments were made. Each consisted of four series. The symbols to be remembered were three-digit numbers. These symbols were picked with equal probability in the various series by the aid of Tables of random numbers out of four lists consisting of 2, 8, 64, and 512 three-digit numbers respectively. A series of symbols selected from one list was to be remembered in the sequence in which they were presented. The presentation was oral.

- a) In the first experiment the number of symbols was not varied, and was kept at eight. The quantity of information in the various series was 1, 3, 6, and 9 bits per symbol or 8, 24, 48, and 72 bits for the entire sequence of eight symbols.
- b) In the second experiment the quantity of information per symbol in /158 the various series was likewise 1, 3, 6, and 9 bits, but the quantity of information in the entire sequence of symbols remain constant at 36 bits, while the number of symbols was 36, 12, 6, and 4 respectively.

c) In the third experiment the quantity of information per symbol was kept constant at 6 bits. The number of symbols presented in the respective series was 4, 6, 8, and 12, while the quantity of all information presented was respectively 24, 36, 48, and 72 bits.

The first experiments showed that, with increasing quantity of information per symbol (1, 3, 6, and 9 bits) and in the entire sequence of symbols, there was also an increase in the number of repetitions necessary for the first error-free reproduction of the entire sequence (1.05; 2.7; 3.8; 4.6), and a decrease in the mean memory capacity per repetition, which was evaluated by the percentage of correctly reproduced symbols related to the total number of symbols presented or, what amounts to the same, by the percentage of information transmitted without noise in one reproduction related to the entire quantity of information presented (95, 37, 26, 21). The experimental curve plotted from these data does not differ markedly from the theoretical curve of a hypothetical re-

lation expressing the function  $y=\frac{1}{x}$ . Thus, these experiments established that the memory capacity is inversely proportional to the quantity of information.

The second experiments showed that an increase in the number of symbols to be remembered, at constant quantity of all information presented, leads to a decrease in the memory capacity despite the decrease in information per symbol, as soon as the information per symbol exceeds 1 bit. At 1 bit per symbol, the memory capacity begins to increase, and there are grounds for supposing that, at a further decrease in information per symbol, the memory capacity will likewise increase and approach 100% despite an increase in the number of symbols. In this case, however, with increasing number of symbols, the number of bits of information into which these symbols can be recoded during the process of recall, will also decrease.

The third experiment showed an inverse relationship between the memory capacity and the number of symbols remembered.

A comparative analysis of the three experiments showed that there is a direct dependence of the number of repetitions, the decrement in information and the reduction in symbols, and an inverse dependence of the memory capacity, on the quantity of all information presented and on the number of symbols being remembered. In this case, the number of symbols exerts its influence if the symbols are not recoded during the process of remembering; otherwise this influence is not exerted by the number of symbols but rather by the number of bits by which the information is recoded. The quantity of information trans— 159 mitted is directly proportional to the information per symbol and the number of symbols reproduced in one repetition is indirectly proportional to it. With increasing information per symbol, the number of symbols reproduced decreases but more information is transmitted by the smaller number of symbols.

The number of symbols being remembered exerts a greater influence on the memory capacity than does the amount of information contained in these symbols. The dependence of the memory capacity on the quantity of information is clearly

manifested when the number of symbols to be remembered is invariant. This is one of the reasons why the dependence of the memory capacity on the amount of information was not discovered earlier and was denied by a number of investigators.

The dual dependence of the memory capacity on the quantity of information and on the number of symbols permits postulating two possible modes by which information is processed during the act of remembering: 1) decrease in the information contained in the symbols being remembered by means of restricting the list of symbols without changing the symbols themselves; 2) decrease in the number of symbols by means of transition to a new and longer list and replacement of the symbols presented by a smaller number of new symbols.

Both of these types of dependence of the memory on the quantity of information and on the number of symbols are of the same character and are expressed by curves that are almost hyperbolic. The same character is also inherent in the dependence of the memory capacity on the time elapsed since the instant of recall (Ebbinghaus effect). Hence we may postulate that the memory capacity similarly depends on the time elapsed since recall, on the extent of the material being remembered, and on the information contained in that material.

#### MEMORY PROCESSES AND THE CODING OF INFORMATION

#### N.I.Ryzhkova (Kharkov)

According to experimental data obtained by a number of investigators, the effectiveness of information coding in the man - machine system is determined by various factors: choice of the list of symbols, character of the problem to be solved by the operator, compatibility of stimulus and reaction, and others. The effectiveness of coding, as a function of these factors, generally was studied in connection with the features of the perception processes. Memory, in such studies, has been represented almost exclusively by its process of cognition. Yet the influence of these and other factors on the effectiveness of information coding, in connection with the features of the functioning of such complex memory processes as recall and reproduction, has received but scant attention from investigators. The subject of the present investigation was /160 the study of these particular processes.

In this project, we investigated the recall and reproduction of information coded by various lists of symbols, both literal and geometrical. These codes were studied in two versions: codes not connected with the information content, or abstract codes; and codes connected to a certain extent with the subject of the communication, or concrete codes. In the experiments we found differences in the recollection and decoding of the symbols, and we found also that these differences depended on the material expression of the code as well as on the character of the relation of the symbols to the content of the coded communication. In this case, the differences between the concrete and abstract variants of the code were more substantial than those between literal and geometrical coding.

In another version of the experiments (performed by G.V.Repkina) it was found that in the solution of operative problems requiring a considerable load on the memory, the most effective codes are those for which larger operative units of memory are easily formed.

Even these few laws suggest that effectiveness of coding may be greatly improved by taking account of the peculiarities of memory in the operator's work. Further than that, it can be assumed that the basic laws of memory may also exert an influence on the methods of coding itself. We will use this assumption as basis in formulating the future problems for our investigation.

In many studies by Soviet psychologists the proposition has been developed that the success of recollection is determined primarily by various methods of logical processing of the material, its grouping in the mind, and so on. Such methods enhance the productivity of memory because the number of definite units of the material being recalled is considerably decreased by the formation of larger generalized units, or "pieces" in it. In these investigations, what was mainly studied were the various ways and means of coding material for its subsequent recall, although this term itself was not employed.

These data of Soviet mnemonic psychology have recently been confirmed in research by J.Miller who established that the memory capacity can be considerably increased by combining a larger number of symbols with a smaller quantity of information. The decisive role in the memory processes is assigned to the coding and recoding of information.

The problem of our present investigation was to study the effectiveness of coding under conditions of a definite grouping of codes, and their generalization without diminishing the volume of information. To solve this problem we developed a technique of two experiments. The object of the first experiment was the comparative study of the effectiveness of unitary, binary, and ternary methods of coding. We assumed that in the binary and ternary code the decrease in a number of basic symbols of the code and their replacement by new parameters would enhance the effectiveness of these codes by comparison with the unitary codes. In a second experiment, the decrease of the number of symbols in the code was accomplished by generalizing some symbols - generic - and subordinating others - special - to them. This method of coding is compared with the code in which the symbols are not generalized. In a later communication we shall present the preliminary results of these experiments.

### ON THE COMPOSITION AND DYNAMICS OF THE OPERATIONS OF MNEMIC ACTIVITY

V.Ya.Lyaudis (Kharkov)

A study of the structure of recall by a functional analysis of the learning process has shown that mnemic activity consists of three operations: The first is orientation in the material being recalled, its categorization, and the establishment of its composition and structure. The second operation is connected with the search for, and isolation of, the corresponding material of the method

of grouping. These two operations form the orienting part of mnemic activity. The performance of these operations assures the optimum course of the process of retention.

Each operation performs here a definite function. In the first operation, the composition of the material being recalled is established, its categorization is accomplished, and the finding of some grouping method is prepared. In the second operation, those links between the elements being recalled, which are of uniform significance for the entire series, are differentiated. This operation prepares directly for establishing the groups and determines the establishment of the intragroup links. The net result is isolation of transformation methods corresponding to some objective characteristics of the material to be recalled. The third operation is the grouping of elements, the reorganization of the material on the basis of intra- and intergroup relations, which were established by the preceding operations. This operation establishes the integral structure of the material reflecting to some extent the prescribed structure.

Each of these operations also performs a certain function in reproduction, ensuring the reliability of this process and decreasing its indeterminacy.

The operations of mnemic activity can be regarded as stages in the decrease of the indeterminacy of the material being recalled and of its subsequent reproduction. These operations yield the most general characterization of 162 the structure of mnemic activity.

As shown by our experiments, the subjective methods of grouping may be extremely varied, ranging from logical classification to the combination of elements based on emotional, pictorial, and other associations.

According to the results of our investigation and also to those of a study of the memory capacity (P.B.Nevel'skiy), the various methods of grouping may be classified according to the attribute: relation of the subjective method of grouping to the objective structure of the assigned material. According to this attribute, all methods of grouping may be assigned to two principal methods of transformation of the material for the purpose of its recollection.

The first method of transformation is connected with a decrease in the indeterminacy of the material on account of the discovery of organization (redundancy) in the assigned material.

The second method leads to a decrease in indeterminacy of the material by introduction of organization (redundancy) by methods corresponding only to some single parameter of the material.

The transformation of the material to be recalled by both methods proceeds on the basis of the performance of the above three operations of mnemic activity. The composition, sequence, and functions of the operations in both cases of transformation of material remain identical, but the character of their implementation differs.

The degree of completeness and development of these operations, their

dynamics during the process of recall, varies considerably, which is expressed in the great variability in the number of repetitions and in the memory capacity.

The dynamics of operations, as shown by the data of our experiments, is determined by two factors:

- 1. The relation of the methods of action objectivized in the material to the subjective methods of action.
- 2. The degree of mastery and generalization of the operations of mnemic action.

It may possibly serve as a more reliable criterion of the optimum nature of the process of recall to take these factors as a whole into consideration.

#### COMPARISON OF VARIOUS METHODS OF RECOGNITION

# M.S.Shekhter (Moscow)

The attention of investigators today is being concentrated more and more on the problems of recognition of "variative" objects. (Examples of variative objects are: the triangle, which may be acute, obtuse, or right; or a let- /163 ter of the alphabet. which may be written in various ways.)

Each variative object has its own distinctive attributes, its "characteristics". A distinctive attribute may either be a single elementary property, or several such properties taken together. Regardless of this difference, each attribute that is distinctive for a given object possesses the peculiarity that it is found only in that object, and for this reason may serve as a basis for the recognition of that object.

The question of the methods of recognition of a variative object is primarily a question of the various distinctive attributes, by which the object of interest can be recognized. In the present experimental study we attempted to compare various distinctive attributes and to evaluate their comparative advantages and disadvantages.

One of the methods of recognition has long been known in psychology, pedagogy, and logic. This is the recognition of a variative object by a distinctive attribute which may be called logical. A distinctive attribute of this kind has at least the following four features. We shall explain them on an example, in which a certain variative object A and its logical distinctive attribute  $\ell$  are given:

l. The attribute of interest in a given case is sufficient and necessary: The presence of the attribute  $\ell$  in the presented object means that this object is an object A, while the absence of the attribute  $\ell$  means that this object is not an object A.

- 2. The attribute  $\ell$  is common to all possible variants of the object A.
- 3. This attribute is also the most detailed in subdivision.
- 4. In cases where the object A is not too simple, in view of the presence of the above three features, the attribute  $\ell$  often has still another feature: It consists of a complex (or set) of several elementary properties taken together, and may be denoted in symbols as the attribute a  $\cdot$  b  $\cdot$  c (a, b, and c being the component properties of the complex).

The recognition of an object by a logical distinctive attribute has a number of advantages: Probably such a method, more than others, is suitable for the organization of the initial cognitive action of the subjects, it ensures a correct evaluation of any new, previously not observed variants of the assigned object, etc. However, it is a question whether the method is optimum in all respects and in particular with respect to the speed of recognition\*.

The present study answers this question in the negative. The attribute in question does have a disadvantage: In order to accomplish the recognition /164 based on this attribute, it is necessary to discover in the presented object several rather than a single property (i.e., to find the properties a, b, and c). This slows the process of recognition, and the delay takes place regardless of whether these properties are noted subjectively or whether they are revealed without cognition, i.e., automatically.

Our experiments show that, even where the subject knows how to recognize the object by a logical attribute, he often prefers to use other distinctive attributes which are free from the above disadvantage. In the psychology of recognition, workers clearly underestimate the role of such distinctive attributes which, although they are not necessary attributes of the given variative objects (in our example, of an object A), are still entirely sufficient for its recognition. This means that the presence of a distinctive attribute of this kind in the object presented permits that object to be evaluated as an object A. although the absence of such an attribute still says nothing whatever about it. Attributes of this kind are sometimes very advantageous. Many of them are integral attributes, i.e., attributes that are elementary and cannot be broken down - at least in the course of the process of recognition - into several properties. Consequently, the use of such integral attributes frees the recognition process of the unwieldiness involved in reliance on a logical distinctive attribute. The process of finding several properties is replaced by the process of finding only a single property.

It is true that the use of attributes of this kind also suffer from certain disadvantages, but these do not completely outweigh the advantages of such attributes.

<sup>\*</sup> Here and hereafter we have in mind the recognition process with positive result: The object presented is evaluated as an object A. In principle, the opposite case is also possible: The object presented is evaluated negatively, i.e., as an object "not A".

Specifically, what attributes can be utilized as integral properties, and will also be sufficient for the recognition of a variative object?

Experiments performed on geometrical figures show that a distinctive attribute of the figure, such as "type", "form", or "shape", "contour" etc., plays a substantial role in the recognition of a given geometrical figure. As a rule, the variative figure has several such attributes which are partial (but not common) attributes of its variants.

It is only natural that any one of these attributes should be sufficient, since it belongs only to the given object (a figure A) and is absent from all other objects (from figures "not A"). Each time the assigned figure is recognized by only one sufficient attribute which, however, does vary from time to time depending on the character of the variants presented. Thus, for the recognition of a given figure in its various concrete forms, several different and sufficient attributes are used.

If many concrete variants of the object A are used in an experiment, this does not mean that the number of distinctive attributes considered must correspond to the number of variants and thus also be very great. The point is that, in certain special cases, the object A may be of about the same "kind" so that the number of integral attributes employed would be many times smaller than the number of all special variants of A employed in the experiment.

#### COGNITION IN THE PROCESS OF SOLUTION OF OPERATIVE PROBLEMS

## D.N.Zavalishina and V.N.Pushkin (Moscow)

In modern cybernetics the work on the duplication of human psychic activity by the machine proceeds mainly in two directions, that of cognition and that of problem-solving. Work by M.M.Bongard and E.M.Braverman was, in particular, devoted to an analysis of the various forms of cognition. The trend of heuristic programming (Newell, Shaw, Simon) now includes the development of the problem of modelling the human method of problem-solving.

Until recently the work on these two problems (cognition and problem-solving) was done separately. Newer research (Minskiy, Samuel), however, show the promise, for cybernetics, of a combination of these two problems.

In work on the psychology of thinking there are materials which distinctly show the significance of cognition as a component of problem-solving. Thus, representatives of Gestalt psychology (Wertheimer) have emphasized that to solve a problem means to recognize a "good structure" and a "bad". The role of cognition has been distinct in studies devoted to the prediction activity in various stages of the solution of a creative problem (A.N.Leont'yev, S.L.Rubinshteyn, Yu.B.Gippenreyter, A.Ya.Ponomarev, K.A.Slavskaya).

The process of cognition as a component of problem-solving possesses a considerable number of specific features as compared with cognition as a component of perception. The fundamental difference between these processes lies

in the fact that, in perception, the object that is recognized has elements which are clearly and visibly interrelated, whereas many intellectual problems, including operative problems, are presented to man in the form of a discrete set of elements. Finding the relations between the elements of this set is a specialized activity and is sometimes highly developed and complex.

This specific form of cognition was investigated on the materials of /166 the "5" game. As the method for objectively recording the thinking process, we used, in particular, motion-picture photography of the eye movements in solving problems. As found by experiment, cognition is merely one of the mechanisms of problem-solving. The forms of its manifestation and the very fact of its occurrence are due to the past experience of the subject and to the character of the objective link between the elements of the problem.

The following forms of cognition in the process of problem-solving were differentiated in an analysis of the data:

- a) Cognition of the subproblems. This form of cognition is related to the development by the subject, during the course of successive solution of a number of problems, of certain special algorithms for the solution of the subproblems. In this case, the subject, striving to simplify the solution for himself, analyzes each new problem from the viewpoint of the methods known to him. Thus, in a new problem, he recognizes subproblems which give him no trouble.
  - b) Cognition of situations encountered earlier.
- c) Cognition, in the present situation, of the final situation in terms of its transformation. Thus, the situation  $\frac{235}{14}$  is perceived as the already solved problem, as the situation  $\frac{123}{45}$ . This form of cognition is the most productive. It is characterized as the dynamic cognition of discrete sets.

It is likewise characteristic that the adjustment to the cognition of subproblems fixes the direction of the analysis and impedes dynamic cognition. In this case, the subject often bypasses the "ready structures", and the solution of the problems will become nonoptimum.

Dynamic cognition, since it is manifested in the course of the solution of an operative problem, substantially optimizes its solution by completely excluding a different type of test and selection of variants. As shown by an analysis of the data, cognition arises at a certain stage of problem-solving. The internal content of dynamic cognition as a process consists in: attempt at direct superposition of the initial situation on a reference standard; evaluation of the attributes of the elements of the problem situation as a discrete set of interrelating the various elements; procurement of a reference standard by transforming the situation.

Thus, cognition - as a component of problem-solving - is a transition from a discrete set to an ordered set through simulation of the possible dynamics of

the elements of the situation.

The investigation of the features of dynamic cognition will encourage the combination of the problem of cognition with the problem of problem-solving, and may be useful in working out a number of theoretical and practical problems of cybernetics.

ON TABULAR ASSIGNMENT AND REORGANIZATION OF ASSOCIATIVE MEMORY

/167

E.T.Golovan' and V.S.Starinets

(Kiev)

The man - machine problem is connected with the formulation of the problem of direct communing of man with the machine.

The machine must learn to construct phrases that are thought out within the limits of the problem under study and must possess an "emotional" function similar to that of man (N.M.Amosov, R.Bernard).

A necessary step in the creation of such an automatic machine is the verification of certain algorithms on the organization and transformation of its associative memory.

Memory is represented in the form of a set of Tables of rank. The Tables  $TQ_1$ ,  $TQ_2$ ,  $TQ_3$  of rank zero are set up on the basis of a limited dictionary and the classification Table of emotions  $T_c$  (E.T.Golovan' et al). The rows and columns of the Table  $TQ_1$  and  $TQ_2$  are filled with elements of the active dictionary.

The associative link of the word  $a_i$  with the word  $a_i$  in  $TQ_i$  is marked by unity (1) at the intersection of the i-row with the j-column, while the link  $a_i \rightarrow a_j$  ( $a_j \rightarrow a_j$ ) in  $TQ_i$  is marked by the coefficient of correlation for the i-row and the j-column.

The rows of the Table TO3 are elements of the set  $\{\Omega_i\}$  of the Table T, and the columns are elements of the dictionary. If the word  $a_i$  is connected with  $a_i$  through  $\Omega_i$ , then at the intersection of the  $\Omega_i$ -row with the a-column is placed 1. Each time we turn to the Table TO4 it is in the form of the assignment of an initial associative game. Such a pair is an element of the learning sequence.

On TQ are assigned two basic algorithms, of the "stretching" of an associative chain and of m-combinatory. The associative chains are represented in the form of graphs. The graphs are minimized by weighting their sides according to the data of TO mand TO3. From the definition of the nodes of the graph and the statistical criteria, we form new associations and destroy the old ones, which is noted by entering the digit 1, and by crossing out the units in TO4 and TO3. The elements of Table TO2 are converted.

The set of elements of the Table TQ with the mutual coefficients of cor-

relation  $k_1 \ge k_{max}$  form a "concept" of first rank and are elements of the Table Tl<sub>1</sub> (a Table of first rank). The Tables Tl<sub>1</sub>, Tl<sub>2</sub>, Tl<sub>3</sub> are constructed by analogy to TO<sub>1</sub>, TO<sub>2</sub>, TO<sub>3</sub>. The algorithms for obtaining the associative links in the Tables of rank 1 are not changed, etc.

An associative pair of Tables of any rank may serve as an input to this system.

The control and supervision of the process of "stretching" the chain", already suspended within the set of Tables, is ensured by a contact of the type man - machine and also by the functioning of the answering unit and of the /168 analysis unit (N.M.Amosov and V.M.Glushkov).

Considerations close to those given above can be used for the construction of a machine for programmed learning (Ye, L. Yushchenko and others).

In the paper the author gives data on the realization of certain of the algorithms worked out.

"The aeronautical and space activities of the United States shall be conducted so as to contribute... to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

-NATIONAL AERONAUTICS AND SPACE ACT OF 1958

### NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546